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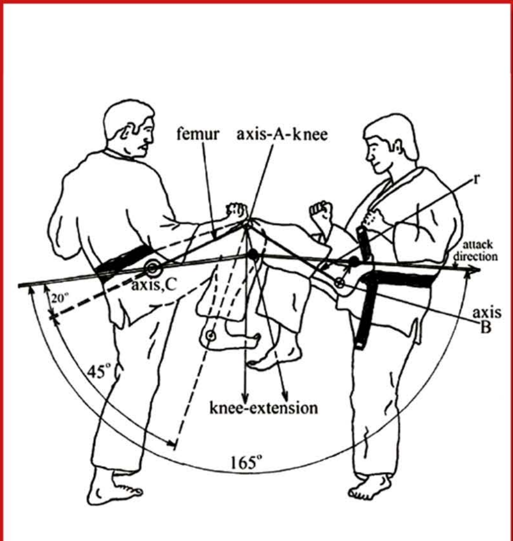
Biomechanics of Human Motion

Applications in the Martial Arts

Emeric Arus, PhD



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Lester Ingber, PhD., Scientific Consultant

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To my late mother, Ana, for giving me the gift of life and teaching me how to be independent, inventive, responsible, and productive in society.

To my son, Emeric Jr., and grandchildren, Sydney Isabella, Sean Matthew, and Dillon Luke, with eternal love.

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A man who seeks perfection perhaps
never finds it, but who
seeks simplicity will
find perfection.

—DR. EMERIC ARUS

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Contents

Foreword

I first had correspondence with Dr. Emeric Arus in October 2009, when he asked me to review his book in progress, *Martial Arts Biomechanics*.

I regularly review papers and occasional books for many scientific journals across several disciplines, and I always have attempted to politely and honestly address short technical queries on my work documented in my http://www.ingber.com archive, but I am also careful on how I commit time to large book projects.

After some correspondence with Dr. Arus, it was clear that he was a master in martial arts. Had already developed a lot of educational material for teaching, and he was dedicated to contributing his knowledge on biomechanics of martial arts with his new book. He explained that this book would be particularly well suited for a broad range of physical education students and athletes with interests in body movement.

I have written many papers and three karate books, so I understood the breadth and depth of what Dr. Arus was taking on for this project. Dr. Arus understood this as well, and his motivation and talent were strong enough to sustain him through some inevitable hard subprojects in developing his textbook.

Over the next two years, Dr. Arus and I were in close touch regularly, and I saw his vision developing into the current textbook. I am proud to know Dr. Arus, honored that he asked me to help by reviewing this book, and excited to see this final product.

The final result of Dr. Arus' efforts is a book that serves many purposes: martial arts students and teachers will find indispensible descriptions of body movement to help them correct techniques and create better combinations of techniques. Students and teachers of anatomy, physiology, and biomechanics will find unique perspectives on their discipline as it relates to the complex body activities found in the martial arts. I hope that many

novices to any of these fields will be motivated by Dr. Arus' book to study their chosen disciplines, sports, and avocations with the same dedication and depth as exhibited in this textbook.

Lester Ingber
PhD Physics, 8th Dan Karate Sensei
Ashland, Oregon
2011

Preface to the Second Edition

It was my pleasure to find out that Taylor & Francis asked me if I would like to work on a second edition of this book. I said yes, especially because I like challenges. This preface almost entirely concentrates on Part IV, Chapter 12, "The Defense and Attack on Vital Points (*Kyusho*) Finger(s) Manipulation," and a new Section 13.3, "The Biomechanics of the Japanese Sword (*Katana*) Defense." In the rest of the book, there are minor corrections with occasional explanations. Chapter 12 is unique because the Vital Point Art (pressure point art) is relatively new in the world. It is important to mention the use of *Katana* as a weapon for killing the opponent or as a weapon in modern times used for demonstration. The use of *Katana* for demonstration is very attractive. In this edition, the author has spread information about the effectiveness of this weapon.

The anatomo-physiological adaptation of an athlete to effort is important to any instructor to prescribe the best fighting regimen for an athlete. The reader may ask about Olympic weight lifting. The anatomo-physiological adaptation of the athlete also is extremely important. In weight lifting, the athlete uses all his physical properties at different times during a competition. For example, before lifting the weight, he uses his concentration and his mental preparedness for the execution of the lift. He must use force and speed and not exclude the technical execution in all that he must have.

In Chapter 12 of this edition, the author emphasizes anatomy and four physical properties, especially energy and force. The author explains in detail when, how, and why a martial artist uses energy or force. In the first edition, under the Aikido techniques, he explained the use of *Kokyu-ryoku* arm-grabbing liberation techniques, but in this edition, the *Kyusho-jutsu*

techniques are even more important than the Aikido techniques. During an attack, using Aikido grabbing techniques, a defender in Aikido can use a simple throwing technique as a liberation technique. In *Kyusho-Jutsu*, it is important to use the liberation *Kokyu-ryoku* techniques because if the defender's arm or hand is not liberated, he cannot rub or strike any of his opponent's pressure points.

In this edition, the author explains when the martial artist should use more energy and less power or force. In the same way, explanation is available for the use of force. There are correct and minutely described explanations of the use of energy and force. Since force is omnipresent in any activity, kinetic energy from potential energy also will be present in our actions, so the question is which physical property (force or energy) initiates the movement in our case, pressing or striking the opponent or some object.

In Section 13.3, "The Biomechanics of the Japanese Sword (*Katana*) Defense," the reader will find challenging descriptions and also a potential challenge with the author about the *Katana* efficiency and defense.

Those who have read the first edition of this book have plenty of examples of the use of physics in fencing, where circular techniques as well as straight executions are available in plenty for anyone who wants to challenge himself.

The author may be reached at International Sendo-ryu Karate-do Federation at www.sendo-ryu.com.

Preface to the First Edition

From the very young age of 13 years I was interested in biomechanics. Of course, I did not know what exactly biomechanics was; however, when I started fencing at 13, I asked myself and my coach why the blade of a weapon is as long as it is, why is it not shorter, why is the blocking called parry and not block, and why are some parries soft and others hard?

My fencing coach, an admirable man, had no college degree and furthermore no biomechanical or even physical education knowledge; he was a hat maker but a pretty good fencing coach. When I finished college at the Institute of Physical Education and Sport in Bucharest, Rumania, specializing in fencing, judo, and track and field, I already knew that biomechanics are the foundation of any coach or instructor's technical knowledge. As an assistant college professor of biomechanics in my country (Rumania), I started to make observations about the biomechanics of martial arts techniques.

Prior to writing this book, I made hundreds of simple tests during my 42 years of martial arts teaching. To this day I have not been able to find any books that completely or partially describe martial arts biomechanics. Sporadically, I have found some publications in scientific journals about biomechanics or the physiology of different martial arts techniques. This is probably the first book that describes the biomechanics of nine martial arts.

In this book, general biomechanical laws related to nine martial arts will be described. This book is directed to be used for undergraduate and graduate students of human movement science, physical education, and fitness as well as college instructors and martial artists alike. The book can be used as a textbook for those students who concentrate on the

biomechanics of sports techniques, because it compares martial arts techniques to different sports techniques.

Part I describes the musculoskeletal anatomy of the most important muscles and their functions. The author concentrates on the descriptions of the larger muscle groups and explains the different roles of the muscles in human mechanics.

Part II describes the biomechanical and physiological foundations of human motion. Chapter 4 describes succinctly the very basic conceptions about lever systems, center of gravity, kinematic chain systems, and Newton's laws. Part III describes the core of biomechanics, which is divided into kinematics and kinetics. Part IV guides the reader into the complexity of martial arts biomechanics. For a better understanding of the described biomechanical laws, theories, and equations described herein, the reader should also consult other biomechanical and anatomical books.

For a better understanding of the biomechanical laws, Parts III and IV present many examples from martial arts and sports activities that emphasize muscular activity related to the technique described. Mathematical equations are kept simple and understandable for any beginner in biomechanics. In Part IV, many techniques and their actions related to human musculature are described in detail.

For more information, please visit www.sendo-ryu.com.

Note: This book contains many photos that show the use of techniques in intense competition. These photos show the real-life practical context of these applications. However, some of these photos are not as "picture-perfect" as other posed photos that were taken under more controlled environments. So the author had to make some choices in some cases with regard to these trade-offs, to deliver what would be the best image for most readers.

Important Note: The author would like to express his opinion about the biomechanical descriptions/explanations in this book, which are scientifically correct. However, they are not substantiated with scientific experiments by the author or his scientific advisor. This book, however, contains many scientific explanations about the examples described herein.

Disclaimer: This book provides information on the biomechanics of nine martial arts. The purpose is to provide information on anatomy, physiology, physics/mechanics, and their relevant equations.

Every effort has been made to make this book as accurate and complete as possible. However, there may be mistakes, both typographical and in content. Therefore, information in this book should be used as a general guide and not as an ultimate source of information on the martial arts.

The reader may be a student of physical education, a martial artist, a college professor, or a fitness enthusiast who can derive in-depth knowledge about the specific martial arts described in this book. Owing to the complexities of the biomechanics of martial arts, the reader may find controversial explanations and even computations. In such instance the reader should use his or her judgment for any additional information to reach an acceptable conclusion.

In a book that impinges on so many fields, it should go without saying that the reader is not responsible for the author's mistakes and is unlikely to agree with everything presented herein.

Throughout this book, "he" is used to refer to instructors, students, and people. This is for ease of reading only and should be taken to mean him or her, where appropriate. The author's intention in capitalizing the first letter of each word in Japanese is for emphasis, contrary to grammar rules. Furthermore, the Japanese terminologies are written in italic letters and/or enclosed within parentheses.

Acknowledgments

I WOULD LIKE TO DEDICATE this book to all martial artists and fitness experts all over the world.

I am extremely grateful to Professor Lester Ingber, a PhD in theoretical physics and an 8th Dan Karate Sensei, who served as a scientific consultant (http://ingber.com and http://alumni.caltech.edu/~ingber).

A special appreciation goes to my very good friend, student, and instructor, Dr. Attila A. Czegeni, 6th Dan, President of the Hungarian Sendo-Ryu Karatedo Federation, for his valuable observations about the mechanical aspects of the martial arts of karate.

Many thanks to my students Emeric Arus Jr., Axel Robinson, Mike Hill, Brandon Carlson, and Brandon Rubic for their patience while serving me as the opponent in many pictures.

I am thankful for the editorial assistance of Andrew Helms and Sydney Isabella Arus.

Most of the pictures have been shot in the author's martial arts gym (Dojo).

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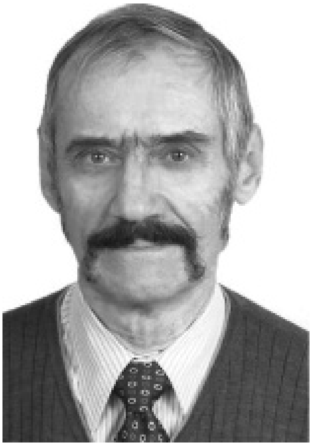
Author



Emeric Arus, PhD, is an internationally known martial arts instructor with over 50 years of background and a wearer of high-degree black belts in several martial arts (Karate 10th degree, Jujutsu 8th degree, Judo 4th degree, Kyusho-Jutsu 7th degree). Dr. Arus is also a former Olympian who occupied 6th place with the Rumanian saber fencing team at the 1960 Rome Olympic Games. The two-time Rumanian fencing champion competed in many international championships where he occupied leading positions.

Dr. Arus is a former college assistant professor of biomechanics and anatomy, in his native country of Rumania. He holds a physical education state diploma from the Institute of Physical Education and Sports, Bucharest (equivalent to an MS), and he has conducted many researches in the field of physical education, fitness, and sports, but most importantly in biomechanics. Dr. Arus is the founder and president of the International Sendo-Ryu Karate-do Federation and the USA Sticky Hands Combat Jujutsu Federation (www.sendo-ryu.com).

The International Sendo-Ryu Karate-do Federation has been recognized by many worldwide martial arts organization as a new, genuine karate style. After coming to America, Dr. Arus earned an MS in physical education from Brooklyn College, New York, and in 2004, at the age of 66, he earned a doctoral degree in human movement science from Atlantic International University of Hawaii.

Prior to and after receiving his doctoral degree, Dr. Arus authored more than 15 articles related to martial arts in different publications that

have been published in the United States and in Europe. Dr. Arus also has written four books about his karate style.

His first book is *Sendo-Ryu Karate-Do Handbook*. The second book titled *Sendo-Ryu Karate-Do*: *The Way of Initiative* has been published in two editions. Dr. Arus recognizes the value of the scientific aspect of many martial arts, without denying the art aspect, which is why he wrote this book. He considers it a culmination of his effort in the field of academics and martial arts. He brings to readers an undeniable value of the scientific aspect of the martial arts.

The author may be reached at International Sendo-ryu Karate-do Federation at www.sendo-ryu.com.

Symbols

Acceleration due to gravity	g Base of support (BoS)
Angular acceleration	α (Greek—alpha) Center of gravity (CoG)
Angular displacement	θ (Greek—theta) Center of mass (CoM)
Angular distance	φ (Greek—phi) Central nervous system (CNS)
Angular impulse	ΔL or F_f Peripheral nervous system (PNS)
Angular momentum	L or H Range of motion (RoM)
Angular velocity	ω (Greek—omega) Center of rotation (CoR)
Average acceleration	$\bar{a}$
Average speed	$\bar{s}$
Average velocity	$\bar{v}$ or υ
Axial rotation	ψ (Greek—psi)
Change	Δ (Greek—delta)
Coefficient of friction	μ (Greek—mu)
Coefficient of kinetic friction	μ_k (Greek—mu)
Degrees of freedom	DoF
Distance (radius)	r
Energy (angular/rotational kinetic)	KE_{ang}
Energy (linear kinetic)	KE
Energy (potential)	E or PE
Force	F
Force of magnitude	F_δ
Gravity	g
Joule	J
Length of path	l
Lever	$\perp$
Linear acceleration	a
Linear displacement	d or s

Linear impulse	*J*, **S**
Linear momentum	*p*
Linear velocity	*v* or υ
Magnitude	δ
Moment of force or moment	M
Moment of inertia	*I*
Newton	N
Newton meter	N · m
Power	*P*
Radian	rad
Pascal	Pa
Torque	Γ or *T* or τ (Greek—tau)
Total sums	Σ (Greek—sigma)
Varies as	∝
Watt	W
Weight	*w*, G
Work	*W* or *U*

I

The Anatomical Foundations of Biomechanics

OUTLINE TO PART I

Part I prepares the reader with general knowledge about biomechanics and human anatomy. In order to have a better understanding of biomechanics, the study of anatomy is extremely important.

The biomechanics of different sport branches have been described in many books. A prime example is track and field about which hundreds of films, scientific papers, and books have been written. The biomechanics of martial arts have not been investigated throughout. In this book, the reader can find questions and answers to many aspects related to mechanical laws adapted specifically to martial arts.

In Part I, the author highlights different characteristics of the bone, joint, and muscles, such as composition, types, and functions. A major portion of Part I describes almost all body parts (musculoskeletal anatomy and their functions) and emphasizes different muscular regions, especially the larger and stronger ones. Bones specifically are not described in this book, but as mentioned earlier in this book, the reader should consult basic anatomical books about bones.

CHAPTER 1

Introduction

1.1 WHAT IS BIOMECHANICS?

The application of forces to living organisms and the investigation of the effects of these forces on a human body or system, including forces that arise from within and outside of the body, is called biomechanics. Biomechanics also includes the study of the structure and function of the biological system by the rule of mechanics applied to muscular activity. Biomechanics is composed of two words, *bios* meaning "life" in Greek, and mechanics.

The term *kinesiology*, which is used interchangeably with biomechanics, is a combination of two Greek words, *kinein* meaning to "move" and *logos* meaning "to discourse." A total meaning is "a discourse on movement," and a definition of kinesiology is the study of muscles and body movement related to anatomy and mechanics.

The title "father of kinesiology" was given to the Greek philosopher Aristotle (384–322 BC), author of several treatises, including *De Partibus Animalium* (On the Parts of Animals) and *De Motu Animalium* (On the Movement of Animals), who described for the very first time the actions of the muscles and disposed them to geometric analysis. Another Greek mathematician and physicist, Archimedes (287–212 BC), developed hydrostatic principles related to floating bodies that are still accepted as valid in fluid mechanics or the biomechanics of swimming.

A Roman citizen named Galen (AD 131–201) was considered to be the first physician for the gladiators. Galen wrote the essay *De Motu Musculorum* in which he described differences between motor and sensory nerves. He

described muscular tonus and introduced the terms *diarthrosis* and *synarthrosis*, which are still used to this day as the correct terminology in arthrology.

The great Leonardo da Vinci (1452–1519), an artist, engineer, and scientist, described the relationship between the center of gravity and body balance. He described the mechanics of standing, walking, and jumping. Another Italian, Galileo Galilei (1564–1643), demonstrated that the acceleration of a falling body is not proportionate to its weight and that the relationship of space, time, and velocity is the most important attribute in the study of motion.

Many other people such as Alfonso Borelli (1608–1679) stated that bones act as levers. Isaac Newton (1642–1727) established modern biomechanics and his laws of inertia, acceleration, and action–reaction are major and valid laws of modern biomechanics. We could mention perhaps hundreds of others who studied human anatomy and mechanics. These are just a few.

Biomechanists were concerned with integrating into their studies a number of different disciplines such as "structural–functional biomechanics," "exercise physiology," and "motor behavior and control."

1.2 IMPORTANCE OF BIOMECHANICS

Mechanics is a branch of physics and engineering that deals with the evaluation of forces responsible for maintaining an object or structure in a fixed position, as well as with the description, prediction, and causes of motion of an object or structure.

The importance of biomechanics for any physical educator is primary. Biomechanics gives information and guidance about the function of the musculoskeletal system with respect to better technical solutions and adaptations to the related environment.

Biomechanics has to work in a tight relationship with exercise physiology. In order to understand the relationship between biomechanics and exercise physiology, here is an example: A marathon runner in order to be efficient in his running must know about leg stride (biomechanics) and the rhythm of breathing (physiology). Another example is taken from martial arts: a Judoka must know exactly every aspect of the *Ukemi*—breakfall techniques. By using the correct biomechanics, the Judoka can reduce the shock with the ground by approximately 80%.

Muscle contractions are guided by physiological functions and different forms of body movement, which again are related to biomechanics. Later on, detailed descriptions about muscular control of the human body will

be provided. In order to know the human potential of resistance against forces that arise from within or from outside of the body, it is important for physical educators to know about body types and especially about the composition of the bones, ligaments, and muscles. Knowing anatomical compositions and physiological functions, a good coach/instructor could avoid wrong executions and guide toward the correct biomechanical paths of certain technical executions.

An explanation is important to know about the difference between the basic knowledge of correct biomechanical executions and new (apparently incorrect biomechanical) technical executions. In this case, if the apparently incorrect biomechanical execution is more efficient versus the "known correct technical execution," then we speak about *style*. By the way, biomechanics dictate the correct technical executions, but style dictates new correct technical executions proved under stress of the competition.

1.3 BIOMECHANICS AND ITS DIVISION

Mechanics has two major fields: *statics*, which considers rigid bodies that are in a stable state of equilibrium, and *dynamics*, which studies objects that are in motion. *Dynamics* can be further divided into *kinematics*, which includes displacement, velocity, and acceleration without taking into consideration the forces acting on the body, and *kinetics*, which relates to the forces that cause motion associated with time and energy spent. Table 1.1 shows the area of study of biomechanics.

1.3.1 Statics

A kinematic chain is said to be in equilibrium when all the links of the chain are in balance. Equilibrium can be (a) *stable*, hanging, sitting, or standing position; (b) *unstable*, standing on one leg; and (c) *neutral*, a ball on the floor. For the maintenance of a stable/static position, there are important factors such as (1) center of gravity (CoG), (2) base of support (BoS), (3) height of CoG, (4) line of gravity, (5) mass of body, and others. All these factors will be described later.

1.3.2 Dynamics

There are three general types of motion: *rectilinear* (translatory), *angular* (rotary), and *curvilinear*. In rectilinear motion, every particle of a body moves the same distance along a straight line parallel to the path of every other particle. The motion of the human body seldom uses rectilinear motion. When a boxer or karateka executes a straight jab, he does not

TABLE 1.1 Biomechanics and Its Division

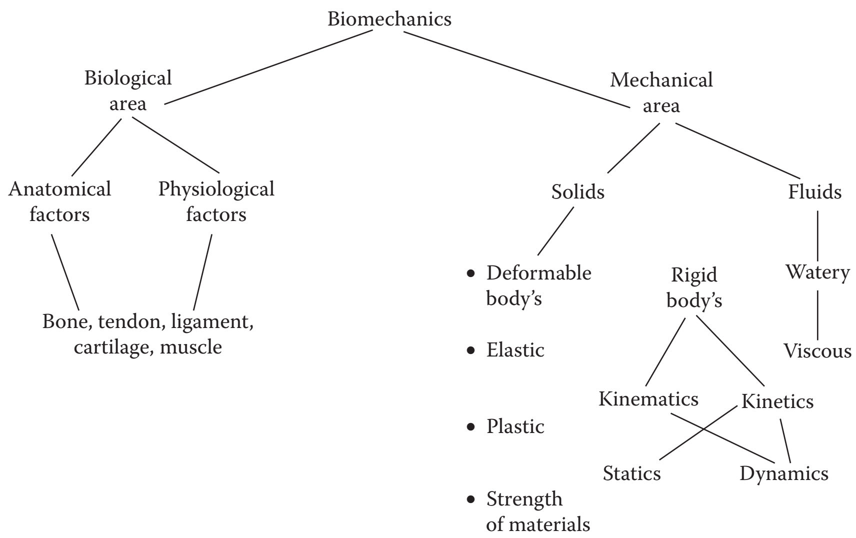


exhibit a complete rectilinear motion. At some point, the jab executions turn into rotary motion.

In angular motion, a body or a part of the body rotates around an axis. The body or the body part travels with the same direction, angle, and time. In curvilinear motion, the body follows a curved path.

CHAPTER 2

The Anatomy of Human Motion

2.1 BONES (OSTEOLOGY)

When we speak about bones in the context of biomechanics, we must always use the other two components of the moving mechanism—joints and muscles. However, in order to know about the potential of resisting against strikes, pressure, bearing weight, and knowing the leverage systems that are basically offered by bones, we have to know the composition and characteristics of the bones.

There are 205 bones (excluding the teeth) in a human skeleton; however, only 177 participate in voluntary movement. The skull bone (22 altogether) is considered as a single bone with reference to the spinal column.

The skeleton consists of two major parts, the axial skeleton and the appendicular (extremities) skeleton. The pelvis can be classified within either the axial or the appendicular skeleton; it is actually an important link between the axial skeleton and the lower extremities. The skeleton supports the body's weight and provides places for muscles to attach. It also protects critical internal organs.

2.1.1 Types of Bones

There are only four bone types—long, short, flat, and irregular. *Long bones* are characterized by a cylindrical rod with large knobby ends. The body has thick, strong walls and contains a medullar canal. There are

several long bones, the clavicle, humerus, ulna, radius, metacarpals, and phalanges of the upper extremity, and femur, tibia, fibula, metatarsals, and phalanges of the lower extremity.

Short bones are solid, small bones. Carpals and tarsals (wrist and ankle bones) are examples. *Flat bones* are the sternum, scapulae, ribs, pelvic bones, and patella. *Irregular bones* are all the bones of the spinal column, including the 24 vertebrae, plus the sacrum and the coccyx.

2.1.2 Composition and Structure of Bones

Bone consists of about 35% of organic material. About 60% is made up of minerals such as calcium phosphate and calcium carbonate, which gives bones the rigidity to resist compression. The remaining 5% is a collagen (protein).

The exterior of the bone is composed of compact, dense tissue and contains small blood vessels and lymphatics for the maintenance and repair of bone tissues. The interior of the bone is spongy. The long bones are adapted for weight bearing. Both the proximal and distal ends typically display protrusions called condyles, tubercles, or tuberosities, which serve as attachments or pulleys for tendons and ligaments.

The bone is covered by a membrane—*periosteum*, which is a connective tissue that covers the outside surface of bones, except at articular surfaces where it is replaced by the articular hyaline cartilage. The periosteum has two layers, an outside layer that is collagenous, and an inside layer that is capable of producing osteoblast, which in turn may develop into osteocytes. Bones form under different conditions and changes can be affected by trauma, hereditary, due to nutrition, disease, or hormonal malfunction.

2.1.3 Growth of Bones

Ossification of bones means the depositing of salt in an organic matrix. The ossification may occur in hyaline cartilage and in existing connective tissue membrane. The primary center of ossification is known as *diaphysis* and occurs before birth. This primary center is at the center of the future bone.

There are some secondary centers for ossification called *epiphysis*. Bone atrophy can be evident even after a short period of time (a few weeks), when the body segment has been in a plaster cast.

Osteoporosis is an age-related disorder characterized by decreased bone mass. Women are at higher risk of osteoporosis because they have less bone mass than men. Early menopause is one of the significant factors

in osteoporosis. Bone growth in diameter occurs most rapidly before maturity but can continue during the life span of an individual.

Growth in length is an ossification of the diaphysis toward the epiphysis. Some theories suggest that very intense work (such as weight training) or long-distance running during early youth may damage the articular cartilage or overload the epiphyses and result in growth disturbances.

Short bones usually grow as if they were an epiphysis; however, they maintain their independent identity. Bone ossification rates differ according to many different factors, such as health, nutrition, endocrine function, race, heredity, and others. None of the epiphyses of the limbs fuse before puberty, but all of the epiphyses will normally be fused before age 21.

2.1.4 Bone Characteristics

The term "mechanical axis" is important in analyzing the bone leverage in a particular motion. The mechanical axis of a bone is a straight line that connects the midpoint of the joint at one end (distal) with the midpoint of the joint at the other end (proximal). The mechanical axis does not necessarily pass lengthwise through the bone. If the articulation has a projection outside of the socket (e.g., hip articulation), then a greater part of the axis may lie outside the bony lever; this is the case of the femur bone.

2.2 JOINTS (ARTHROLOGY)

The connection of two bones is called a *joint* or *articulation*. Joints are classified as (a) immovable or *synarthrodial*, (b) slightly immovable *amphiarthrodial*, and (c) freely movable or *diarthrodial* (Table 2.1). Those joints that have lubrication by having a joint cavity are called *synovial* joints. The first two types have no real joint cavity. The third type has a joint cavity and is subdivided into seven other types.

Figure 2.1 shows different types of articulation. Some of the articular surfaces are covered with a layer of hyaline cartilage. This cartilage acts as a shock absorber and prevents direct wearing on bones to ensure a better and comfortable fit. It has no nerve or blood supply. These cartilages have different names, such as *glenoid labrum* of the shoulder joint and the *semilunar cartilages* or *menisci* of the knee. Under pressure, the cartilage secretes lubricant.

A ligamentous wrapper called the capsule or capsular ligament is attached firmly to both bones of the joint and surrounds it completely. This capsular ligament is lined internally by a thin vascular synovial membrane, which secretes synovial fluid into the joint cavity. This fluid

TABLE 2.1 Joint Classification

Sort	Type	Name	Actions
No joint cavity	a. Synarthrosis	Fibrous	Two bones grow together
	b. Amphiarthrosis	Ligamentous	Slight movement permitted (mid-radio-ulnar joint)
		Cartilaginous	Bones are coated with hyaline cartilage (symphysis pubis, body of sternum)
Have joint cavity	c. Diarthrosis	Synovial	
		1. Gliding joint	Nonaxial. Allows gliding or twisting intercarpal and intertarsal joints
		2. Hinge joint	One axial. A concave surface glides around a convex surface (elbow joint)
		3. Pivot joint	One axial. A rotation around a vertical or long axis is allowed (atlantoaxial)
		4. Ellipsoid joint	Biaxial. Ball and socket joint allowing flexion, extension, abduction, adduction, circumduction (not rotation)
		5. Condyloid joint	Biaxial. A spheroidal ball and socket joint can perform rotation
		6. Ball and socket joint	Triaxial. Shoulder and hip joints
		7. Saddle joint	Triaxial. Joint of the thumb

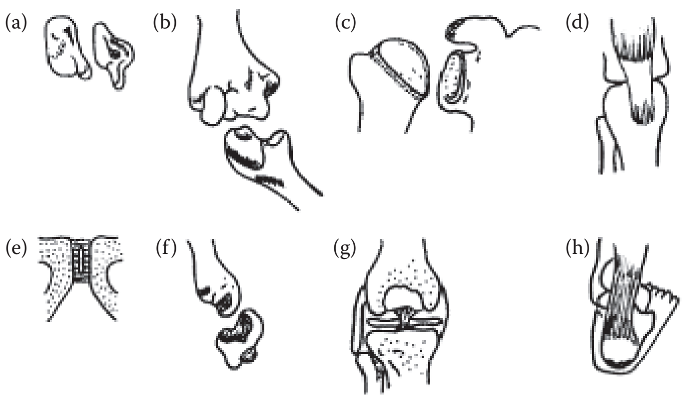


FIGURE 2.1 Different types of joint connections. (a) Plane—intercarpal, (b) hinge—elbow, (c) ball and socket—shoulder, (d) ligament—bone to bone, (e) pubis, (f) saddle—thumb, (g) meniscus—knee, and (h) Achilles tendon—calcaneus.

provides nourishment to the articular cartilage and protects the joint from internal hydrostatic stress.

Injury to the joint causes profuse secretion of the synovial fluid, which can result in swelling. Ligaments are tough and absolutely nonelastic, providing a bond between two bones, and limiting their range of movement. Each synovial joint contains at least one male and one female articular surface.

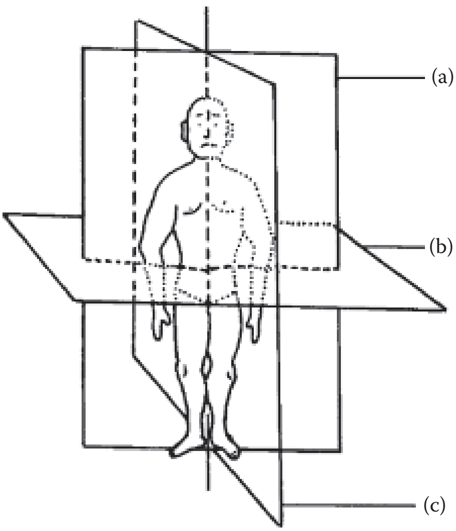
The majority of the muscles are inserted at very small angles. A large component of muscular force is usually directed along the bone toward the joint and tends to reinforce the joint by pulling the bones together.

Tendons are fibrous connective tissues serving to attach muscles to bones and other parts. Tendons are surrounded by a cylindrical sac consisting of two layers of connective tissue.

2.2.1 Terminology of Joint Movements

Human and animal anatomical segments are moved into different directions, planes, and axes. Kinesiologists describe different motions according to the anatomical body standing position, which is: standing erect with the feet together, arms at the side, and the palms facing forward.

The *sagittal plane* (Figure 2.2) divides the body into left and right parts. The *coronal* or *frontal plane* divides the body into anterior (*ventral*)



Abduction is a sideward movement from the midline or sagittal plane. *Adduction* is the inverse movement of abduction. The segment approaches the midline or sagittal plane of the body for example, moving back a laterally held arm to the body.

Rotation can be described as *medial* or *lateral*. They occur in the same plane, generally in the transverse plane around a vertical (longitudinal) axis. *Circumduction* is a movement in which a body part describes a cone with the apex at the joint and the base at the distal end of the body part.

A typical motion of circumduction occurs when an arm is swinging like a windmill. The term *hyperextension* means a continuation of extension farther from the normal anatomic position.

FIGURE 2.2 (a) Frontal (coronal) plane, (b) transverse plane, and (c) mid-sagittal plane.

and posterior (*dorsal*) parts. The *transverse plane* divides the body into superior (*cranial*) and inferior (*caudal*) parts.

The terms *medial* or *lateral* refer to the area of the body closer, medial, or further, lateral, from the midline. Similarly, *superficial* refers to the surface of the body and *deep* refers to far from the surface. The terms *proximal* and *distal* indicate a closer joint connection to the limb involved or further connection from the limb involved.

Flexion is the movement in a joint that causes a decrease in the relative angle between the two segments. *Extension* is the opposite movement to flexion.

Range of motion (RoM) may be limited by ligaments (including the joint capsule), muscle contraction, joint arrangements, and spindle muscle mechanism. *Flexibility* (the common synonym for range of motion) is not usually a general factor and is basically specific to each joint. It should be carefully noted that the term *flexibility* refers more to articular components, and the term *elasticity* refers more to muscular components and their contractility of the actin–myosin muscle filament interaction. Flexibility, as well as elasticity, will decrease with advanced age.

2.3 MUSCLES (MYOLOGY)

2.3.1 Muscle Types

Muscles are generators for mechanical work. The mechanical work comes from the stored chemical energy. There are generally three types of muscle. All these muscle tissues are affected by the same kind of stimuli and produce an action potential very soon after stimulation. They have the ability to contract depending on their initial length and the velocity of contraction.

They have the ability to maintain muscle tone, they will atrophy as a result of inadequate blood circulation, and they can hypertrophy in the case of overload training. Muscle tissue properties include *extensibility*, *elasticity*, *contractility*, *excitability*, and *conductivity*.

Skeletal muscle fibers have differences in metabolic and contractile properties. Type I, or red fibers, are slow-twitch oxidative (SO) fibers. They are characterized by a slow contraction time and high oxidative (aerobic) for long endurance-type activities. Type IIA fibers are for medium oxidative (FOG) (aerobic) and high glycolitic (anaerobic)-type activities.

Type IIA is characterized by high-intensity contractions, such as middle-distance running activities. Type IIB, or white fibers, are for low oxidative (aerobic) and high glycolitic (FG) fibers (anaerobic)-type

activities. Type IIB is characterized by very-high-intensity contractions such as weight lifts and short-distance sprinting.

2.3.1.1 Smooth Muscle

This is an involuntary muscle and makes up the walls of the hollow areas such as the stomach and the bladder and also various tubes such as the circulatory system veins and arteries. It has a slow contraction time compared to the skeletal muscle.

2.3.1.2 Striated Muscle (Skeletal Muscle)

They are composed of thread-like fibers and alternating dark and light bands. Each fiber is a multinucleated cell that can be as long as 30 cm or even more and 10–200 μ diameter (1 mm = 1000 μ). In a human body, there are approximately 270 million striated muscle fibers. They are under voluntary control. Their primary function is to maintain body posture and help body movement.

2.3.1.3 Cardiac Muscle

This type of muscle has structural and functional similarity to both skeletal and smooth muscle. The cardiac muscle can be considered a functional syncytium.

2.3.1.4 Composition and Shapes of Striated Muscle

Adult body weight is made up of 30–40% of striated muscles. Muscles contain 70–75% water, approximately 20% proteins, and 5% organic and inorganic substances. Protein contains contractile elements, such as myosin, actin, actomyosin, tropomyosin, and troponin. The structural elements are albumins, myoglobines, and others. Organic substances are glycogen, lipids, and phosphocreatine (PCr), and inorganic substances are Na^+, K^+, Ca^{2+}, Mg^{2+}, etc. The voluntary muscular system includes approximately 434 muscles and only 75 pairs are involved in the general posture maintenance. There are different shapes of muscles (Figure 2.3) such as long, strap-like (sartorius), spindle-shaped (brachialis), fan-shaped (pectoralis major), and quadrate/rhomboidal (pronator quadratus) and the rhomboid muscles. Figure 2.3 shows the various shapes of muscles.

2.3.1.5 Muscle Attachments

Units of 100–150 muscle cells/fibers are bound together with a connective tissue called *perimysium* to form a bundle termed *fasciculus*. It should

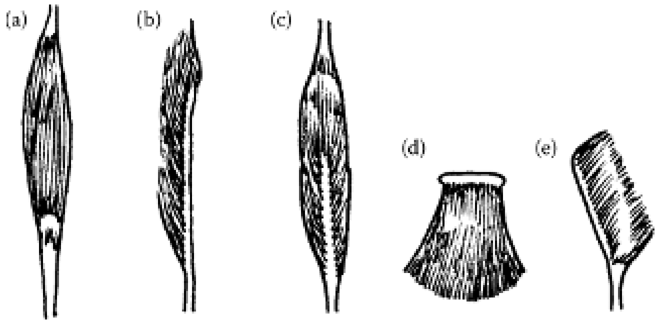


FIGURE 2.3 (a) Fusiform or spindle, (b) penniform, (c) bipenniform, (d) fan-shaped, and (e) rhomboidal or rectangular.

be carefully noted that there is a clear distinction between *ligaments* and *tendons*.

Both ligaments and tendons are connective tissues of a dense fibrous type; however, *ligaments* are used to connect bony components to bony components. Tendons are used to connect muscles to bones. These two types of fibrous tissue bands can be collagen/white tissue type or elastin/yellow tissue type.

Several fasciculi bind together to form a larger unit. These units are enclosed in a covering of *epimysium* to form a muscle attachment. The central part of the muscle attachment is called the belly. Basically, muscle attachments are described as "origin" and "insertion."

The origin is characterized by stability and is closer to the bone. It is usually the more proximal of the two attachments. The insertion is usually a distal attachment and it includes a pretty long tendon. The bone that the muscle's tendon inserts into is the one that originates the move. A tendon collects and transmits forces from many different muscle fibers onto a small area of the bone. The site of the tendinous attachment is normally marked by a rough tubercle on the bone. The aponeurosis gives rise to a skeletal line or ridge at its attachment.

2.3.1.6 Muscle Insertions and Levers

Muscle insertions, whether proximal or distal, are the place where the force is applied to the bone. Muscles attach to bones at some distance from the joint (e.g., the distal attachment of the biceps muscle of the arm is on the bicipital tuberosity of radius). The resistance, however (e.g., a weight in the hand), is usually applied some distance further away from the joint

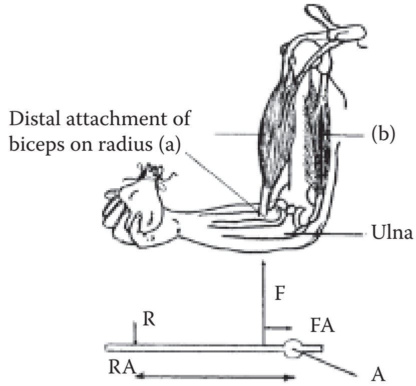


FIGURE 2.4 (a) Biceps, (b) triceps. F, active force of the biceps; FA, force arm; R, weight or resistance; RA, resistance arm; A, axis or fulcrum.

axis. The muscle force lever and weight resistance lever form a third-class lever system in the body (Figure 2.4).

2.3.2 Basic Structure of Striated Muscle

A muscle fiber is a lengthened cell enclosed in *sarcolemma*, which is covered by a thin porous membrane that sticks to an outer network of dividing reticular tissues called *endomysium* (Table 2.2). The sarcolemma keeps bordering fibers from merging into a single, jelly-like mass. So, the muscle fiber can act as a separate unit and decide on admitting or excluding the passage of ions.

Within each muscle cell is specialized protoplasm called *sarcoplasm*. It contains calcium-storing *sarcoplasmic reticulum*. The basic structural unit of the muscle fiber is the *sarcomere*. Sarcomeres are units of compartments between two adjacent dark, thin Z discs or line (synonymous with Krause's membrane). The Z disc transversely bisects the myofibril of each muscle fiber. Figure 2.5 shows a skeletal muscle.

TABLE 2.2 Composition and Functions of Some Muscle Compartments

Compartment	Relevant Biochemical Components	Function
Sarcolemma	Permeable membrane	Protection and impulse conduction/excitation
Endomysium	Connective tissue	Binds fibers together
Sarcoplasm	Calcium storage	Liberation of Ca^{2+}
Myofibrils	Actin and myosin	Contraction
Mitochondria	Phosphorylation and oxidation	Steady aerobic activity or recovery from oxygen debt

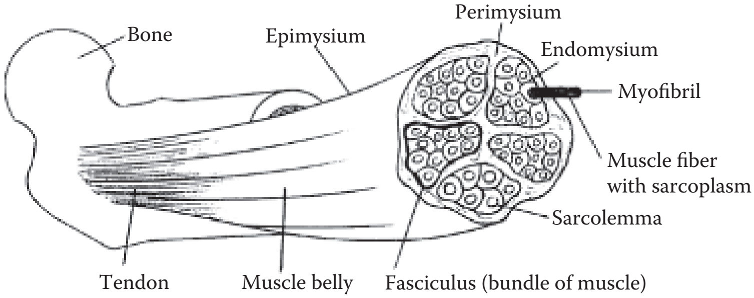


FIGURE 2.5 Cross section of a skeletal muscle and its connective tissues. The myofibril is composed of myosin and actin (contractile element).

The Z discs or line sticks to the sarcolemma, stabilizing the entire muscle fiber. When an electrode is applied to the Z line, a contraction occurs with the two adjacent half-sarcomere as they approach each other. Myofibrils run parallel to each other and to the long axis of the muscle fiber, merging into the sarcolemma at the end of the cell.

The A bands contain only thick *myosin* protein filaments. The I bands contain only thin *actin* protein filaments. The middle of the I band is the Z line, so the I band extends left and right into the border of the A bands, which is at the end of the thick *myosin* filaments. The H zones include the area from between the two *myosin* and ends in the interior of the *myosin* protein filament. If the muscle goes into a state of rigor (stretching), then the filaments usually tear apart in the I band because these filaments are thinner. The M (middle) discs indicate the positions in the middle of the sarcomere. The *titin* filaments are the stabilizers of the *myosin* filaments (see more explanations in Figure 5.1 in Chapter 5).

Inside the cell are the *mitochondria*, slender microscopic filaments 0.5 μm in diameter. They are the source of energy of the cell and are involved in protein synthesis and lipid metabolism. Approximately 95% of the ATP (adenosine triphosphate), the energy necessary for contraction, is produced here. The ATP is important for the myofibril. Athletes who train aerobically have more and larger mitochondria to increase the production of aerobic ATP.

Whole muscle fibers are from 10 to 200 μm in diameter (1 μm = 1/1000 mm). Myofibrils range from 0.5 to 2 μm in diameter. The myosin filament is about 0.01 μm in diameter and the actin filament is about 0.005 μm.

2.3.3 Muscle Fiber Function

When a muscle fiber is activated by its motor neuron, it will act in a variety of ways:

1. A muscle fiber can develop tension within itself.
2. A muscle fiber will shorten.
3. Sometimes the motor programs in the central nervous system (CNS) do not activate a muscle that could help with a given movement. There are many motor programs in the CNS previously learned and stored. A motor program with a different motor movement (skill) is activated with or without sensory feedback and correction.

2.3.3.1 Other Roles

If a muscle undergoes a shortening contraction, it is said to be a mover (or *agonist*) for the joint action that results. If a muscle's contraction tends to produce a joint action opposite to some given joint action of another specific muscle, then the muscle has an *antagonistic* role. An extensor muscle is agonistic to a flexor muscle, for example, the biceps and triceps muscles are an antagonistic pair.

When muscles are most effective in a certain joint movement, they are said to be *prime movers*. Those muscles that help but are less effective are named *assistant movers*. However, the designation of a muscle as a prime or assistant mover is unclear at this time.

A muscle that is said to be a *fixator* or *stabilizer* is an anchor muscle; it supports a bone or body part from where an active muscle has a firm base to pull. For instance, to open a door, elbow flexion may be needed, and if the scapula, for example, is not stabilized, the contraction of the biceps muscle may cause a pulling forward of the shoulder girdle (dislocation) rather than an opening of the door.

We can find similar examples in a Judo contest. During Judo contests using off-balancing *(Kuzushi)*, opponents push or pull each other, but most of the time they pull each other than push each other. So, during the pulling actions, in addition to the biceps and the brachialis muscle acting as a flexor, there are stabilizer muscles of the shoulder girdle that prevent the dislocation of the shoulder joint. There are four muscles that are the major stabilizer of the shoulder girdle, *supraspinatus*, *infraspinatus*, *teres minor*, and *subscapularis*. They are called the "rotator cuff." Each of them

has the origin on the scapula and the insertion on the humerus head (see the individual muscles described under Section 3.3).

Infraspinatus and teres minor rotate the humerus laterally. The subscapularis is the strongest and the largest muscle of the rotator cuff. It prevents the head of the humerus to be pulled upwards by the deltoid, biceps, and long head of triceps. This muscle medially rotates the humerus.

The term *synergist* means when a muscle acts along with some other muscle(s) as a part of the team. A *neutralizer* is a muscle that contracts in order to counteract, or neutralize, an undesired action of another contracting muscle. The term *relaxation* may refer to a state of inactivity or a phase during which the force of contraction is diminishing. Even a relaxed muscle has a very low level of firmness; however, this state is known as *tonus* or *muscle tone*.

2.3.3.2 Spurt and Shunt Muscles

There is a general understanding between kinesiologists, that skeletal muscles act as *spurt* or *shunt* muscles. *Spurt* muscles have their proximal attachment far from the joint axis. Spurt muscles possess a line of pull across a joint that favors torque. They are considered to be "prime movers." The biceps brachii and brachialis in flexing action are considered as *spurt* muscles.

Shunt muscles have their proximal attachment near the joint axis. Their greater part of their contractile force is directed along the bones. Their layout tends to pull the joints together, making these muscles stabilizers. The brachioradialis is a *shunt* muscle. It is a strong flexor muscle of the elbow. This muscle has a protective role during centrifugal action because of the role it plays in flexing the forearm during an isometric contraction.

2.3.3.3 Movement Types

An *active* movement is produced by the subject's own muscular activity. Any body movement that takes place without continuing muscle contraction is categorized as *passive*. There are three types of passive movement:

- *Manipulation*, when another person or an outside force causes the person's body parts to move. There is no gravity involved. Physical therapists distinguish passive or manipulative exercise from "assistive" and "resistive" exercise.

- *Inertial*, which is described as a continuation of a previous established movement and there is no simultaneous muscular contraction.

Inertial movement includes air resistance, tissue viscosity, frictional influences, and others.

- *Gravitational*, movement that is actually a form of manipulative movement. It results from an acceleratory force that is constant in direction and magnitude. Some examples include free fall, the vertical component of the free flight of a jump, and the temporary flight of any aerial gymnastics.

The following are active movements:

- *Ballistic* movement makes use of repetitive and rapid bouncing motions initiated by strong muscular contraction and continued by momentum. Ballistic movement may be terminated by one of the three modalities: (a) interference with an external object, (b) reaching the limit of motion, and (c) contracting of antagonist muscles.
- *Dynamic balance* refers to body equilibrium in motion. It should not be confused with static body balance. *Dynamic balance* or equilibrium is maintained either on a moving surface or while moving the body through space. The movement occurs when spindles detect deviations from a desired position of balance and initiate a servomechanism to make corrections.

Muscular contraction is another type of movement. When muscular contraction occurs and tension is developed, but there is no change in the length of the muscle, the contraction is said to be *isometric*. When a muscle develops sufficient tension to overcome a resistance, so that the muscle visibly "shortens" and moves a body part in spite of given resistance, it is said to be in *concentric* contraction.

When a given resistance overcomes the muscle tension so that the muscle actually lengthens, the muscle is said to be acting *eccentrically*. When a heavy weight is slowly lowered to the floor, the biceps brachii acts eccentrically. A karate kick is executed eccentrically.

CHAPTER 3

Functional Anatomy and Biomechanics

3.1 THE HEAD

It is well known that human locomotion related directly to biomechanics has three subdivisions which were described in Chapter 2. They are bones, joints, and muscles. This triple complex unit (TCU) cannot exist separately when we speak about any movement type. In the following chapters describing the TCU, the author will concentrate mostly on describing the insertions, actions, interactions, and innervations of the muscles; however, the characteristics and actions of the bones and/or joints will be described only briefly.

The author's discretion will be to focus on large bones, ligaments, and muscles and specifically those bones, ligaments, and muscles which have the major role in transmitting force, maintaining balance, intervening in acceleration, and spending energy. Here is a simple example taken from karate. When kicking occurs, obviously the quadriceps femoris with the femur bone has more importance in delivering impact force than the toes of the same leg. But by the same token, in judo the fingers have almost the same importance in executing an off-balance technique compared with the humerus, radius, or ulna bone, and their mass of muscles.

Under this section, the head has less importance in locomotion than the neck area of the head, which is the nape (nuchal portion). Of course, the head which contains the brain has the utmost importance in guiding

any action of the human being. This action is the thinking process which guides any motor act be it speaking, writing, eating, mimicking, walking, running, jumping, swimming, tumbling, rolling, fighting, and so on. The reader can ask what else the head can do in biomechanical terms. We can say not much.

The head has two distinctive portions: The *cranium* is the portion of the skull that encloses the brain which is named *neurocranium* and consists of eight bones. There are single ones, such as frontal, occipital, sphenoid, and ethmoid bones. The paired bones are two temporal and two parietal bones. The *splanchnocranium* is the portion of the skull derived from the visceral part and has 14 bones. Here we describe only three of them. The *vomer* is a single bone, situated vertically at the back part of the nasal fossa, forming part of the nasal septum. The *sphenoid* bone is situated at the anterior part of the base of the skull, articulating with all the other cranial bones and binding them strongly together. The *ethmoid* is a spongy bone, has a cubical form and is situated at the anterior part of the base of the cranium.

Only two bones, the mandible (lower jaw) and the hyoid, are mobile. The rest are united. The mandible has an important role in mastication. The hyoid bone or complex of bones is situated at the base of the tongue and supports the tongue and its muscles. The hyoid bone should not be confused with the so-called Adam's apple which is formed by the thyroid cartilage.

The hyoid complex intervenes in mastication, breathing, and the talking process because it is connected to the muscles of the tongue, pharynx, suprahyoid, and subhyoid muscles. The head can make the following movements which are executed primarily by the neck: Flexion–extension, rotation, circumduction (some authors deny this possibility), and lateral inclination.

3.2 THE NECK

In biomechanics, the neck's movement is described in connection with the vertebral column and the thorax. The vertebral column and the thorax with its sternum have a direct connection with the neck.

The neck has more than 40 muscles connected to the head, sternum, and the clavicle bone. Only those muscles which have significant importance in the head movement and the upper part of the thorax will be described here. Figure 3.1 shows the most important neck muscles.

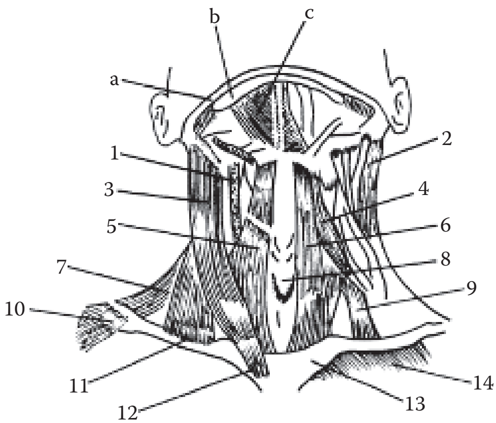


FIGURE 3.1 a. Skin of the neck (platysma); b. base of the mandible; c. mylohyoideus; 1. carotid artery; 2. splenius cervicis; 3. sternocleidomastoideus; 4. omohyoideus; 5. sternothyroideus; 6. sternohyoideus; 7. trapezius; 8. trachea; 9. scalenus anticus; 10. deltoideus; 11. sternocleidomastoideus insertion on the clavicle; 12. sternocleidomastoideus insertion on the manubrium (sternum); 13. clavicle; 14. pectoralis major.

3.2.1 Lateral Region of Neck Muscles

The *sternocleidomastoideus* muscle is one of the most important muscle of the neck region. It is the longest muscle, very strong, and it is easily palpable by the fingers. This muscle can be found on both sides of the neck.

Insertion: The origin of this muscle is on the manubrium of the sternum (one part) and on the superior side of the median third portion of the clavicle (second part). The distal insertion of this muscle is on the mastoid process of the temporal bone of the head and on the superior nuchal line (external occipital protuberance). Interestingly, the majority of the origins of the muscles start at the top level of the human body and the distal insertion are on the lower part of the body.

The way to describe the attachment of muscles to bones is that they have an *"origin" (proximal attachment)* and a *"distal insertion" (distal attachment).* These terminologies can be used in either way and will be used throughout this book.

The deep part of the sternocleidomastoideus covers the carotid artery, internal jugular vein, and the pneumogastric or vagus (Xth cranial) nerve. It is important to mention that the action of the vagus nerve has a double

function such as a motor and sensory function and has a wider distribution than any other cranial nerves.

Action: When one muscle is contracted then the head inclines toward the same side and the face is turned to the opposite side. When both sides of the muscle are contracted then the head and neck flex and are helped by the muscle *rectus capitis anterior*. Sternocleidomastoideus also is an erector of the thorax. Sternocleidomastoideus has the innervation assured by cranial nerve XI.

The *scaleni* are three deeply situated muscles on each side of the neck, extending from the tubercles of the transverse processes of the third through sixth cervical vertebrae to the first or second rib. They are known as *scalenus anterior (anticus), medius,* and *posterior*.

Action: Contraction of the scalene muscles on one side will incline the vertebral column on the same side. Contraction of the scalene muscles on both sides of the neck will increase the rigidity of the vertebral column. Scalene muscles help during inspiration and also intervene at the flexion process of the vertebral column.

3.2.2 Median Region of Neck Muscles

There are two groups of muscles, *suprahyoid* and *subhyoid*. From the group *suprahyoid* there are *digastricus,* a pair of muscles having two bellies separated by a tendon that extends from the anterior inferior margin of the mandible to the temporal bone which serve to open the jaw. The digastricus muscle has a role in mastication and deglutition.

Other muscles such as *stylohyoideus, mylohyoideus, geniohyoideus*, and the *subhyoid* muscles such as *sternohyoideus, sternothyroideus, omohyoideus,* and *thyrohyoideus* have a role in mastication, deglutition, and raising or lowering the larynx with the intervention of the hyoid bone. There are also two other muscles. The *rectus capitis lateralis* inclines the head laterally and *rectus capitis anterior* flexes the head upon the neck. These two muscles are situated prevertebral.

3.3 THE SHOULDER COMPLEX

The shoulder region/complex or girdle includes the following bones: Two clavicles, two scapulae, and according to most authors, the sternum (manubrium part). These bones are responsible for the transmission of forces from the upper extremities of the body. The shoulder girdle is an open mechanical system, the left and the right sides can move independently.

The clavicle articulates with the manubrium of the sternum and also with the first rib. The clavicle acting as a mechanical arm, maintains the glenohumeral joint at its correct distance from the sternum. The clavicle is a prolonged S-shaped bone. The sternum and clavicle are united by the *sternoclavicular* joint (Figure 3.2).

The scapula is connected to the clavicle as mentioned before and holds the humerus head in its glenoid cavity. The scapula has the following movements:

Elevation is an upward movement of the scapula with the vertebral border remaining approximately parallel to the spinal column. This movement occurs mostly in the process of lifting the shoulders in a hunching gesture. *Depression* is the returning process from the elevation.

Abduction is a lateral movement of the scapula executed away from the spine. *Adduction* is a medial movement of the scapula toward the spinal column. *Upward tilt* is a turning of the scapula on its frontal–horizontal axis. The scapula posterior surface faces slightly upward. *Downward tilt* is the returning of the upward tilt.

Upward rotation when the scapula's glenoid fossa faces a little bit upward. *Downward rotation* is the opposite action of the upward rotation. The *glenohumeral joint* consists of a nearly hemispherical humeral head and the relatively shallow glenoid cavity on the lateral aspect of the scapula. The glenoid labrum is a fibrous structure around the perimeter of the glenoid cavity and serves to improve stability to the joint.

There are several other joints related to the scapulohumeral/shoulder girdle joint (Figure 3.3a and 3.3b). The *coracoacromial* ligament is like a

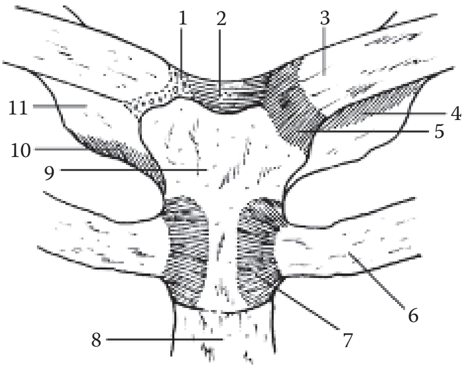


FIGURE 3.2 Sternoclavicular joint. 1. Articular disc; 2. interclavicular ligament; 3. clavicle; 4. costoclavicular ligament; 5. sternoclavicular ligament; 6. second rib; 7. sternocostal ligament; 8. body of sternum; 9. manubrium; 10. cartilage of the 1st rib; 11. first rib.

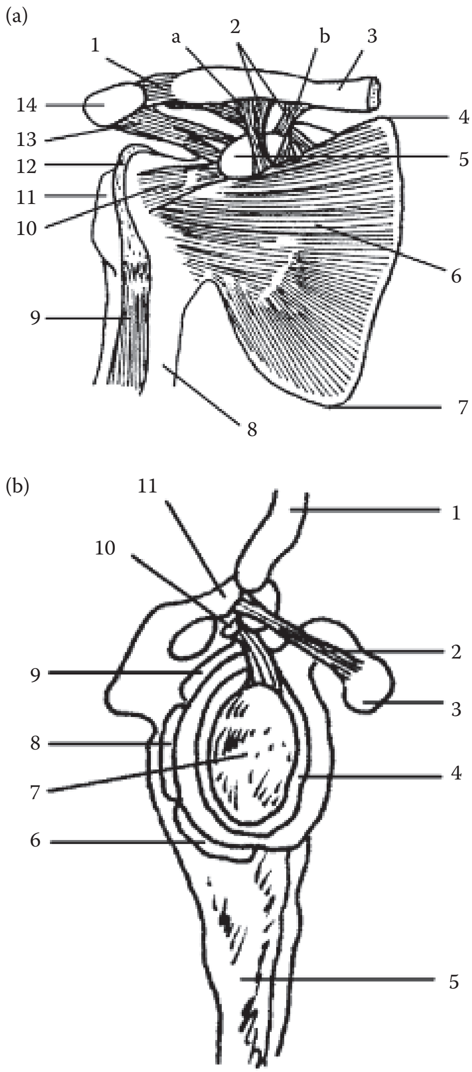


FIGURE 3.3 (a) Ventral view, right shoulder. 1. Acromioclavicular ligament; 2. coracoclavicular ligament (a. trapezoid ligament, b. conoid ligament); 3. clavicle; 4. superior border of scapula; 5. coracoid process; 6. musculus subscapularis; 7. inferior angle of scapula; 8. humerus; 9. biceps brachii; 10. coracohumeral ligament; 11. greater tubercle; 12. biceps brachii tendon (long head); 13. coracoacromial ligament; 14. acromion of scapula.

(b) Lateral view, right shoulder. 1. Clavicle; 2. coracoacromial ligament; 3. coracoid process; 4. middle glenohumeral ligament; 5. scapula; 6. teres minor tendon (origin); 7. glenoid cavity; 8. infraspinatus tendon; 9. supraspinatus tendon; 10. biceps brachii tendon; 11. acromion.

triangular fibrous fan. One side is connected to the top of the acromion (acromial process) and the other side is connected to the coracoid process. The acromial process is on the top of the scapula on the posterior side, and the coracoid process, which is a tuberosity, a kind of hook, is also on the top of the scapula but is on the anterior side.

In addition to the coracoacromial and glenohumeral joints, there are nine more so said microligaments strictly related to the shoulder complex: *Acromioclavicular, acromiohumeral, acromioscapular, acromiothoracic, coracoclavicular, coracohumeral, scapuloclavicular, scapulohumeral,* and a very short and broad *coracoglenoidian.*

Movement of the glenohumeral joint is defined with respect to the humerus, but movement of the humeral head in relation to the surface of the glenoid cavity also occurs. During rotation, the point of contact on the glenoid cavity always remains the same, but the point contact with the humerus varies. Basically the center for humeral rotation changes continuously during motion.

Muscles around scapulohumeral joint forms many so-called micro girdles which maintain the tonicity of the scapula. There are three groups of muscles:

1. *Descendant fibers*, made up of the *trapezius, levator scapulae* are elevators and the *rhomboideus minor* and *major* which are slightly elevators of the scapula.
2. *Horizontal fibers,* made up of the *serratus anterior* and the middle portion of *trapezius.*
3. *Ascendant fibers,* made up of the *pectoralis minor, serratus anterior* (inferior portion), *trapezius, pectoralis major,* and *latissimus dorsi* (engages when the body is in a suspended position from the arms). The muscles mentioned above will be described later on.

In this section on the shoulder complex, we will study the following muscles: *Deltoideus, trapezius, supraspinatus, infraspinatus, teres minor, teres major,* and *subscapularis.* These muscles are shown in Figure 3.4a and 3.4b. Many anatomy, biomechanics or kinesiology books describe the *biceps brachii, brachialis, coracobrachialis,* and *triceps brachii* under the shoulder complex. In this book the author describes these four muscles in Section 3.4, The Muscles of the Arm.

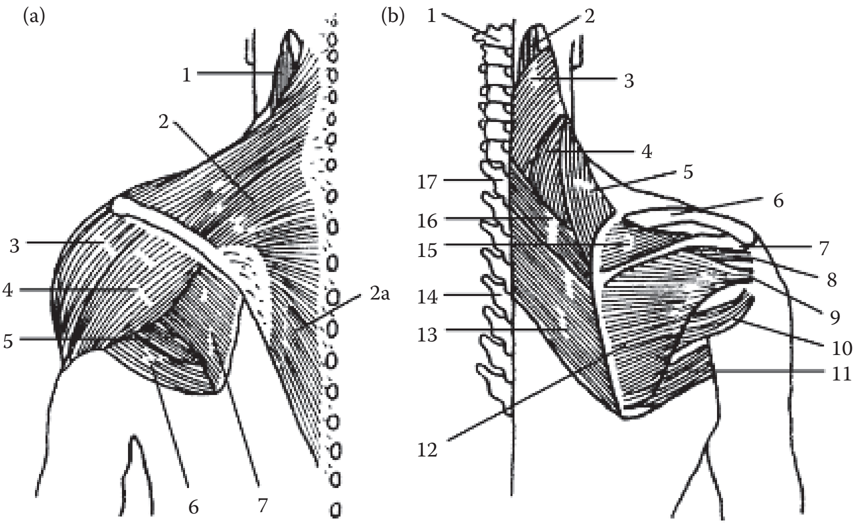


FIGURE 3.4 (a) Left shoulder dorsal muscles (superficial). 1. Semispinalis capitis; 2. and 2a. trapezius; 3. deltoideus (middle fibers); 4. deltoideus (posterior fibers); 5. teres minor; 6. teres major; 7. infraspinatus.

(b) Right shoulder dorsal muscles (deep). 1. First cervical vertebra (atlas); 2. semispinalis capitis; 3. splenius capitis; 4. splenius cervicis; 5. levator scapulae; 6. clavicle; 7. acromion (acromioclavicular joint); 8. suprasinatus insertion; 9. infraspinatus insertion; 10. teres minor insertion; 11. teres major; 12. infraspinatus; 13. rhomboideus major; 14. fifth thoracic vertebra; 15. supraspinatus; 16. rhomboideus minor; 17. first thoracic vertebra.

Musculus deltoideus is the most superficial and voluminous muscle of the shoulder complex. This muscle covers the scapulohumeral joint and has a triangular shape.

Insertion: Has three origins according to the three parts of the deltoideus. The *anterior* muscle fibers originate on the anterior/lateral of one-third of the clavicle. The *middle* muscle fibers have its origin on the lateral part of the acromion process. The *posterior* muscle fibers originate from the spine of the scapula. The distal insertion is on the tuberosity of the humerus that is approximately in the middle part of the bone.

Action: The *anterior fasciculus* performs forward projection, internal rotation, and horizontal adduction of the humerus. The *middle fasciculus* performs exclusive abduction of the humerus. The *posterior fasciculus* performs extension, lateral rotation, and horizontal abduction of the humerus. The deltoideus innervation is given by axillary nerve (circumflex) (C5, C6).

The (C5, C6) indicates the origin of the nerves. In this case C5 and C6 are the fifth and sixth cervical vertebrae. Similarly, T1 or L5 are seen (1st thoracic and 5th lumbar vertebrae). Trauma to the shoulder complex during contact sports, such as football, judo, and hockey can cause the subacromial bursae to develop an inflammation called bursitis that requires immediate treatment in order to avoid chronic bursitis.

Musculus trapezius has a triangular shape similar to deltoideus. This muscle covers a large part of the back along the vertebral column on both sides.

Insertion: The origin is at the external occipital protuberance/ligamentum nuchae C7 through T12 spinous processes. Distal insertions are made by upper muscle fibers that descend obliquely and inserts at the lateral third of the clavicle, more precisely at the acromioclavicular joint. Middle muscle fibers insert on the spine of the scapula. Lower muscle fibers are inserted at the root of the spine of the scapula.

Action: The upper portion of the trapezius is an upward rotator and elevator of the scapulae. Also it has an action of inclination of the head to the right or left side where the muscle is contracted. The middle portion of the trapezius is a retractor of the scapulae and inclines the vertebral column. The lower portion of the trapezius is a depressor and upward rotator of the scapula.

The trapezius innervation is given by cranial nerve XI (accessory nerve) and branches of C3 and C4. The trapezius has a major role in the muscular tonicity maintenance of the shoulders.

Musculus supraspinatus occupies supraspinous fossa/pit of scapula. *Insertion:* The origin at the supraspinous fossa of scapula. The distal insertion is at the greater tubercle of humerus (superior facet). Supraspinatus is covered by the trapezius muscle.

Action: Stabilization of the humerus head into glenoid fossa and abduction of humerus. The supraspinatus innervation is given by suprascapular nerve (C5, C6). This nerve is a collateral branch of the brachial plexus.

Musculus infraspinatus occupies infraspinous fossa of scapula which is the origin of this muscle. The distal insertion is at the greater tubercle of the humerus (middle facet). It is covered by the trapezius and deltoideus muscles and has a connection medially with teres major and teres minor muscles.

Action: Laterally rotate the humerus. It has a lesser role in the extension of the humerus. The infraspinatus innervation is given by suprascapular nerve (C5, C6).

Musculus teres minor is situated laterally of infraspinatus. *Insertion:* Its origin is at the upper two-thirds of the axillary border of scapula (posterior part). The distal insertion is behind the scapulohumeral joint on the greater tubercle of humerus (inferior facet). It is covered partially by deltoideus. *Action:* Lateral rotator of the humerus. It has a lesser role in the extension of the humerus. Innervation is assured by axillary (circumflex) nerve (C5, C6).

Musculus teres major is a prolonged, powerful, and voluminous muscle. *Insertion:* The origin is at the inferior angle of the scapula (dorsal surface) and the lower one-third of the axillary border of the scapula. The distal insertion is on medial part of the bicipital groove of the humerus. The teres major has connection with the posterior margin of the base of axilla. The superior margin of the muscle is separated from teres minor by a triangular space with the base on the humerus. Teres major is covered by the latissimus dorsi.

Action: Teres major is a stronger extensor of humerus then teres minor. It is also a rotator intern and adductor of the humerus. Innervation is assured by the thoracodorsal nerve from the brachial plexus network of lower cervical nerves (C5, C6, and C7).

Musculus subscapularis is situated in subscapular fossa of the scapula. *Insertion:* Its origin is the subscapular fossa. The distal insertion is on the lesser tubercle of the humerus. *Action:* Rotator intern and adductor of humerus. Subscapularis is part of the "rotator cuff" with the following muscles such as the supraspinatus, infraspinatus, and teres minor. The rotator cuff action protects the glenohumeral joint. The subscapularis has a connection with the posterior wall of axilla. Innervation is assured by subscapular nerve (upper and lower portion) (C5, C6).

In conclusion, here are the different actions of the shoulder complex muscles as a result of their synergistic and antagonistic actions:

- Deltoideus and supraspinatus are abductori of the humerus.
- Infraspinatus and teres minor are rotatori extern of the humerus.
- Teres major and subscapularis are adductori and rotatori intern of the humerus.

Figure 3.4a and 3.4b shows the most significant muscles of the shoulder complex.

3.4 THE MUSCLES OF THE ARM

As mentioned earlier in this chapter the *biceps brachii, brachialis, coracobrachialis*, and *triceps brachii* will be described. The biceps brachii, corachobrachialis, and triceps brachii adhere to the scapula. The brachialis adheres to the humerus.

Musculus biceps brachii is a long muscle having two distinctive heads; a long and a short head. *Insertion:* The short head has its origin on the coracoid process of scapula. The long head has its origin on the supraglenoid tubercle of the scapula. Both heads will unite and become a single thick muscle that descends to the elbow joint. From there, they insert distally through a tendon on the tuberosity of the radius (bicipital aponeurosis). Between the tendon and tuberosity, there is a bursa bicipitoradialis. This bursa is like a pouch and it secretes serous fluid.

Biceps brachii anterior is covered by brachial fasciae and skin. The posterior is situated on musculus brachialis. Between the brachialis and the biceps brachii is the musculocutaneous nerve. At the elbow joint level, the biceps brachii is in contact with the epitrochlear part which is at the inner condyle of the humerus. At this level, lateral muscles such as brachioradialis, extensor carpi radialis longus, and extensor carpi radialis brevis are in close proximity to the distal insertion of biceps brachii.

Action: Musculus biceps brachii has an action on the arm and forearm. Flexion of the forearm on arm, but flexion is complete only if the forearm is in a supine position. Some authors use the terminology "flexion of elbow." This is incorrect because the elbow does not move. It has the role of a fulcrum. Biceps brachii is a strong supinator of the forearm. Biceps brachii has an action of adduction on the humerus through the short head and through the long head is an abductor. Innervation is given by musculocutaneous nerve.

Musculus brachialis is a broad and bulky muscle situated anterior and inferior behind biceps brachii. *Insertion:* The origin is on the lower half of the anterior and lateral shaft of the humerus. Distal insertion is on tuberosity and coronoid process of ulna. *Action:* This muscle is the strongest flexor of the forearm. Innervation is given by musculocutaneous nerve (C5, C6, and C7).

Musculus coracobrachialis is situated medial from the short head of the biceps brachii. *Insertion:* The origin insertion is through its tendon on the coracoid process of the scapula. This insertion is shared with the short head of the biceps brachii. Muscular fascicles descend and insert distally on the median and middle part of the humerus.

Coracobrachialis has connections: Medial with the axillary vascular and nervous group and lateral with the short head of biceps brachii. It is perforated by the musculocutaneous nerve. Between the coracobrachialis and subclavicular muscle is the bursa coracobrachialis. *Action*: Adductor and forward projector of the humerus. Innervation is given by the musculocutaneus nerve.

Musculus triceps brachii is a voluminous muscle and has three heads, a long head and two short heads. *Insertion:* The long head (caput longum) origin insertion is on infraglenoid tubercle of the scapula and adheres to shoulder articulation through the capsular joint. The lateral head (caput laterale) origin insertion is on the septum intermuscular brachial lateral and on the posterior part of the humerus above the spiral groove where the radial nerve is located. The medial head (caput mediale) origin insertion is on the posterior part of the humerus below the spiral groove.

These three portions of the triceps descend and insert distally by a common and powerful tendon on the olecranon process of ulna (posterior part). Triceps brachii is covered partially by the posterior fibers of the

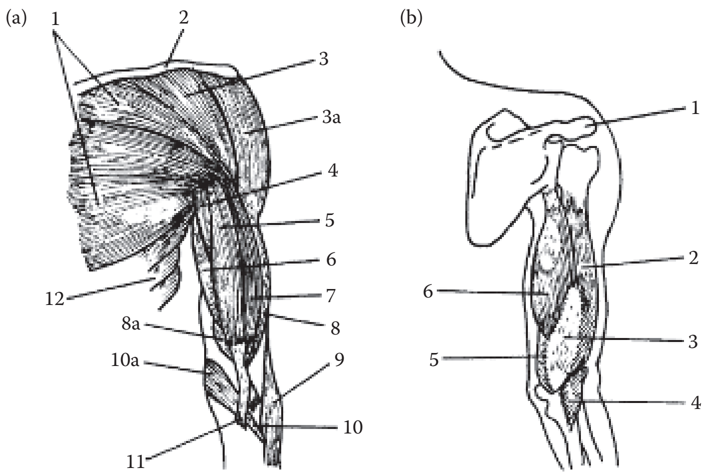


FIGURE 3.5 (a) Left arm ventral muscles. 1. Pectoralis major; 2. clavicle; 3. deltoideus (anterior fibers); 3a. middle fibers; 4. coracobrachialis; 5. biceps brachii; 6. triceps; 7. biceps brachii (long head); 8. and 8a. brachialis; 9. brachioradialis; 10. and 10a. pronator teres; 11. biceps insertion; 12. serratus anterior.

(b) Right arm dorsal muscles. 1. Acromion; 2. triceps (lateral head); 3. common triceps tendon; 4. anconeus; 5. triceps (medial head); 6. triceps (long head).

deltoid muscle. The anterior is separated by the radial nerve and the deep brachial artery of the humerus.

Action: Extensor of the forearm, adductor of the humerus through its long head. Innervation is given by radial nerve.

Musculus anconeus is a short muscle. It is located at the elbow joint. This muscle assists the triceps muscle to extend the forearm at the elbow. It has a reduced role of stabilizing the ulna during supination and pronation. Figure 3.5a and 3.5b shows the most important muscles of the arm.

3.5 THE ELBOW AND THE RADIOULNAR COMPLEX

The majority of the anatomical books describe the wrist together with the hand action. In this book, the author has decided to describe the elbow, radioulnar and wrist anatomy, and their actions together. Most of the muscles which act on the forearm also act on the wrist.

Muscles involved in the movement of flexion and extension of the elbow can be described in many ways. Emphasis will be put on the muscles which act directly or indirectly to bring about the flexion of the forearm on the upper arm. However, approximately half of these muscles do have flexion of the wrist or the phalanges. Flexor muscles are more important than extensor muscles; because flexion of the elbow or flexion of the wrist is related to lifting up objects or grabbing objects. These activities are common, daily tasks of humans.

Here are the following muscles which are active in flexing the forearm and the wrist which are found on the anterior part of the forearm. They are arranged in three layers. The *superficial layer* contains *pronator teres, flexor carpi radialis, palmaris longus,* and *flexor carpi ulnaris.* The *middle layer* contains *flexor digitorum superficialis*. The *deep layer* contains *flexor digitorum profundus, flexor pollicis longus,* and *pronator quadratus.*

It should be mentioned that there are four muscles of the lateral region of the forearm. *Superficial layer,* contains *brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis* and *deep layer* has one muscle, the *supinator.* Because the brachioradialis is a very strong and important muscle it will be described here.

Musculus brachioradialis is the most superficial and anterolateral muscle. It is one of the most powerful muscles of the elbow and radioulnar complex region. The bulk of the muscle is located on the lateral and upper part of the radius, very close to the elbow. Martial artists use it as a pressure point (Kyusho in Japanese) to press on the superior branch of

the radial nerve which can be found approximately in middle of the bulky muscle. Pressure on this point causes excruciating pain to a person.

Insertion: The origin of this muscle is on the lateral supracondylar ridge of humerus. Distal insertion is on the styloid process of radius. Brachioradialis has connection with brachial and bicipital lateral grooves of the biceps in which lie the radial nerve and radial artery. *Action:* It is a strong flexor of the elbow. It is also a supinator only when the forearm is in a forced, prone position. It is a pronator when the forearm is in a forced supine position. Innervation is given by the radial nerve (C5, C6).

Musculus pronator teres is a superficial muscle and lies between the muscles of brachioradialis and flexor carpi radialis. Pronator teres is covered by brachioradialis toward its distal insertion. *Insertion:* The origin of this muscle is on the medial epicondyle of the humerus. Pronator teres converge down obliquely and laterally. It will insert distally on the middle and lateral part of the radius. *Action:* Pronator of forearm and assists in flexion of elbow. Innervation is given by median nerve (C6, C7).

Musculus flexor carpi radialis is a long muscle but its tendon covers at least half of the total length of the muscle. *Insertion:* The origin of this muscle is on the medial epicondyle of the humerus. Distal insertion is on the second metacarpal base and has also a very small insertion on the third metacarpal base. Flexor carpi radialis has a connection with pronator teres which is above and situated laterally. The palmaris longus which is also above but medially situated from the muscle flexor carpi radialis.

At the proximity of the wrist, the superficial part of the muscle which is mostly the tendon is covered by fascia antebrachium and the skin. The tendon part of the muscle covers the muscle flexor digitorum superficialis and flexor pollicis longus.

Between the ligament of brachioradialis and flexor carpi radialis lay the radial artery and median nerve. This is the portion where people can test the pulse. *Action:* It is a weak flexor of the elbow but is a strong flexor of the wrist and an abductor of the wrist, too. When the palm is in an extended position then it is a pronator. Innervation is given by the median nerve (C6, C7).

Musculus palmaris longus is a very long and thin muscle. *Insertion:* The origin of this muscle is on the medial epicondyle of the humerus. The distal insertion is on palmar aponeurosis and on flexor retinaculum. *Action:* It is weak elbow flexor and assists flexion of the wrist. Innervation is given by the median nerve (C6, C7).

The following muscles belong also in the flexor group, but they are mostly flexors of the wrist and adductors of the palm or fingers. Because they have no action on the elbow, they will be just mentioned and later on a few of them will be described in Section 3.6, The Wrist and Hand Unit.

Here are muscles such as *flexor carpi ulnaris, flexor digitorum superficialis, flexor digitorum profundus,* and *flexor pollicis longus.* These muscles are also found on the anterior part of the forearm. Figure 3.6a and 3.6b shows the muscles of the anterior part of forearm.

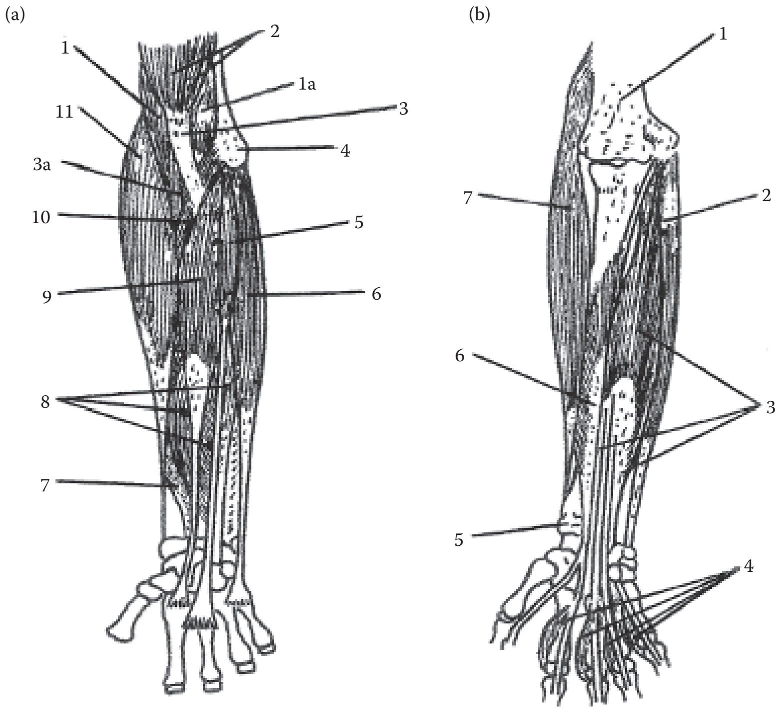


FIGURE 3.6 (a) Ventral part of the right forearm (superficial muscles). 1. and 1a. Brachialis; 2. biceps brachii; 3. bicipital aponeurosis; 3a. tendon of biceps brachii; 4. medial epicondyle of humerus; 5. palmaris longus; 6. flexor carpi ulnaris; 7. flexor pollicis longus; 8. flexor digitorum superficialis; 9. flexor carpi radialis; 10. pronator teres; 11. brachioradialis.

(b) Ventral part of the right forearm (deep muscles). 1. Humerus; 2. flexor carpi ulnaris; 3. flexor digitorum profundus; 4. lumbricalis; 5. radius; 6. flexor pollicis longus; 7. brachioradialis.

On the posterior part of the forearm there are muscles which act as extensors of the wrist and partially of the forearm. These are the extensor muscles of the forearm: *Anconeus, extensor digitorum, extensor digiti minimi, extensor carpi ulnaris, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus,* and *extensor indicis.*

Musculus anconeus is a small muscle with a trapezoid shape. It can be found in the elbow region. It can be considered to be a part of the triceps muscle. *Insertion:* The origin is on the lateral epicondyle of the humerus. The distal insertion is on the olecranon process and upper posterior surface of the ulna. It is a very superficial muscle and it is covered by skin. *Action:* It is an extensor of the forearm and assists the triceps brachii. Innervation is given by the radial nerve.

Musculus extensor digitorum is situated on the lateral and superficial part of the forearm. *Insertion:* The origin of this muscle is on the lateral epicondyle of the humerus. The bulk of the muscle descends and inserts distally with four ligaments at the expansion of fingers II–V.

At the metacarpophalangeal joint, each ligament expands and adheres at the articular capsulae on the middle phalanges. The ligaments of the fingers III, IV, and V are interconnected. Extensor digitorum cannot extend the distal phalanges. Extension of the interphalangeal joints is due to the lumbricals and interossei. When the muscle is over contracted, then finger and wrist extension occurs.

Action: Extensor of proximal phalanges, adductor of the hand and abductor of the fingers. Innervation is assured by radial nerve (C6, C7).

Musculus extensor digiti minimi is situated medially from the extensor digitorum and joins its tendon. *Insertion:* Origin is on the lateral epicondyle of the humerus. Distal insertion is an extensor expansion of little finger with extensor digitorum tendon. *Action:* It is the extensor of little finger and contributes to the extension of the hand. Innervation is assured by radial nerve (C6, C7).

Musculus abductor pollicis longus is situated laterally and is one of the most powerful muscles of the forearm. *Insertion:* The origin of this muscle adheres to the interosseus membrane of the ulna and the dorsal part of the radius. The distal insertion with its tendon adheres to the first metacarpal base. *Action:* Abductor of the thumb and assists also with wrist abduction. Innervation is given by radial nerve (posterior interosseus) (C6, C7).

Musculus extensor pollicis longus and *extensor pollicis brevis* are extensors of the thumb. Their origin of insertion is at the interosseus membrane of the ulna and radius. The distal insertion of the pollicis longus is on the

distal phalanx of the thumb. The distal insertion of the pollicis brevis is on the base of the proximal phalanx of the thumb. Their actions are at the distal respective proximal phalanx level. They are innervated by the radial nerve.

Musculus extensor indicis has its origin at the lower level of the interosseus membrane and ulna posterior part. Distal insertion is on the dorsal part of the proximal phalanx of the index finger. *Action:* Extensor of the index finger.

Musculus extensor carpi ulnaris has its origin at the lateral epicondyle of the humerus and on the posterior/proximal part of the ulna. The distal insertion is on the base of the fifth metacarpal bone. It is an extensor and adductor of the wrist.

The other two extensors are *musculus extensor carpi radialis longus* and *extensor carpi radialis brevis*. For both of these muscles, the original

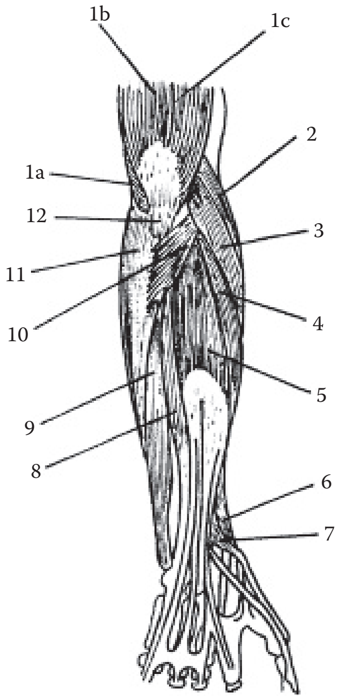


FIGURE 3.7 Extensor muscles covering the dorsal part of the right forearm (superficial muscles). 1a. Triceps brachial (medial head); 1b. triceps brachial (long head); 1c. triceps brachial (lateral head); 2. brachioradialis; 3. extensor carpi radialis longus; 4. extensor carpi radialis brevis; 5. extensor digitorum; 6. abductor pollicis longus; 7. extensor pollicis brevis; 8. extensor digiti minimi; 9. extensor carpi ulnaris; 10. anconeus; 11. flexor carpi ulnaris; 12. triceps tendon.

insertion is on the lateral epicondyle of the humerus. They are very long muscles. The distal insertion of the extensor carpi radialis longus is on the base of the second metacarpal bone. The distal insertion of the extensor carpi radialis brevis is on the base of the third metacarpal bone. Their action is the extension of the wrist. Figure 3.7 shows the extensor muscles from the dorsal part of the forearm (they are mostly superficial muscles).

3.6 THE WRIST AND THE HAND UNIT

The author considers that in many technical executions of different martial arts, the major aim is to execute efficiently and forcefully any action in which the larger muscles have the principal role. However, when we speak about skillful execution, for example, directing a thrust with a foil (fencing) or executing a cut on the forearm with a saber (fencing), the muscles of the wrist and the hand are very important.

In martial arts, such as karate, judo, wrestling, and kick boxing where the force and speed dominate in almost any action, the larger muscles are more important than the hand unit fine muscles. Hand muscle actions are for accuracy, finesse, and skill in a confined area. Larger muscle segments are important for force delivery under different circumstances, such as using speed, maintaining CoG, and maintaining the maximal physiological state of the athlete and other factors.

The hand muscles can be found only on the palmar part and between metacarpals (interossei and lumbricals). The dorsal part of the hand is represented by the dorsal interossei. The palm has 19 muscles and they are grouped in three regions:

(1) The *thenar* region which is the fleshy eminence at base of thumb. These are muscles that provide motion for the thumb. (2) The *hypothenar* eminence, popularly named “sword hand” or “knife hand,” which provides motion for muscles serving the little finger. (3) The *middle of the palm* which includes the interossei and lumbricals.

The *thenar* eminence has four muscles: *Musculus abductor pollicis brevis, opponens pollicis, flexor pollicis brevis*, and *adductor pollicis*. Their actions are indicated by their name.

The *hypothenar* eminence has four muscles, too. They are: *Musculus palmaris brevis, flexor digiti minimi, abductor digiti minimi*, and *opponens digiti minimi*. Their actions also are indicated by their name.

The *middle region* of the palm has the tendons of the flexor muscles, such as *flexor digitorum superficialis, flexor digitorum profundus,* and *flexor pollicis longus*. Let us describe succinctly these three muscles:

Musculus flexor digitorum superficialis is a very long muscle covering the distance from the humerus bone to the end of the middle phalanges of four fingers. *Insertion:* The origin has two insertions. One is on the front side of the medial epiycondyle of the humerus bone and continues with the second insertion on the medial border of the coronoid process of ulna for the same muscle segment. The second origin with the second muscle segment is on the radial head and upper two-thirds of the anterior border of radius.

The distal insertion continues in one muscle segment dividing into four tendons and then into two slips, each of which inserts into the sides of the

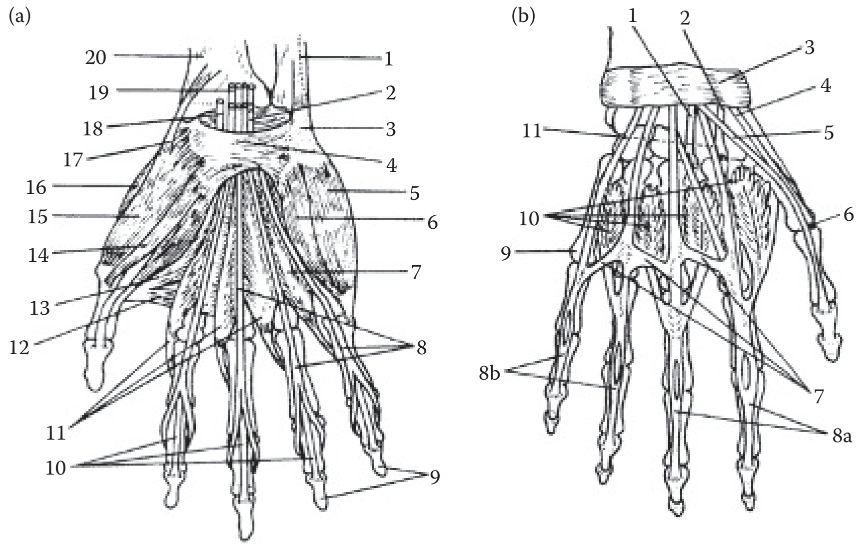


FIGURE 3.8 (a) Superficial palmar muscles. 1. Flexor carpi ulnaris; 2. tendons of flexor digitorum superficialis; 3. and 4. flexor retinaculum; 5. abductor digiti minimi; 6. flexor digiti minimi brevis; 7. fourth musculus lumbricalis; 8. tendons of flexor digitorum superficialis; 9. distal phalanges of fourth and fifth fingers; 10. tendons of flexor digitorum profundus; 11. musculus lumbricalis; 12. adductor pollicis (transverse fibers); 13. adductor pollicis (oblique fibers); 14. flexor pollicis brevis; 15. abductor pollicis brevis; 16. opponens pollicis; 17. abductor pollicis longus; 18. flexor pollicis longus; 19. tendons of flexor digitorum profundus; 20. radius bone.

(b) Muscles of the hand (dorsal part). 1. Tendon of extensor carpi radialis brevis; 2. tendon of extensor carpi radialis longus; 3. extensor retinaculum; 4. tendon of extensor pollicis brevis; 5. tendon of extensor pollicis longus; 6. distal insertion of extensor pollicis brevis; 7. intertendinous connections of extensor digitorum muscle; 8a. and 8b. tendons of extensor digitorum; 9. fifth metacarpal bone; 10. dorsal interosseus muscles; 11. tendons of extensor digitorum.

middle phalanges of the four fingers. *Action:* Flexes the middle phalanges of each finger and additionally flexes the wrist. Innervation is assured by the median nerve (C7 and T1).

Musculus flexor digitorum profundus can be found under the musculus flexor digitorum superficialis. *Insertion:* The origin is on the upper two-thirds of the medial and anterior surfaces of the ulna and interosseus membrane. The distal insertion is on the anterior surface and the bases of distal phalanges of four fingers. *Action:* It is a flexor of the four distal phalanges assists flexion of the wrist. Innervation is assured by the median nerve to radial two fingers (C8 and T1) and the ulnar nerve (C7 and T1) to ring and little fingers.

Musculus flexor pollicis longus occupies the deep layer (third layer) of the palm. Its tendon with other flexor muscles passes through the carpal tunnel. *Insertion:* The origin is on the middle part of the anterior surface of the radius and on the interosseus membrane. Also it sometimes has an origin on the medial epicondyle of the humerus. The distal insertion is on the distal phalanx of the thumb. *Action*: Flexion of the distal phalanx of thumb. Innervation is assured by the median nerve (C7 and T1).

There are four muscle *lumbricals* which covers approximately the four metacarpals 2–4 and *musculus interossei palmares* covers metacarpals 5, 4, and 2.

Musculus interossei dorsales covers the dorsal part of the hand including all metacarpals. The hand muscles have stronger flexor actions than the extensor. Figure 3.8a shows the superficial palmar muscles and Figure 3.8b shows the dorsal muscles of the hand.

3.7 THE VERTEBRAL COLUMN AND ITS REGION

3.7.1 Structure and Function

The vertebral column is the most important functional unit for executing any movements because it is the guiding center, including the brain, of course, for any activity which integrates the majority of sensory and motor nerve activities. All nerves within the trunk and limbs emerge from the spinal cord, and it is the center of reflex action containing the paths to and from the brain. The spinal cord has a center portion of gray matter and is surrounded by white matter which is more voluminous than the gray matter.

The gray matter has the shape of H with a posterior and an anterior horn in either half. The anterior horn is composed of motor cells from which the fibers making up the motor portions of arising peripheral nerves. The sensory nerves emerge from the posterior horns.

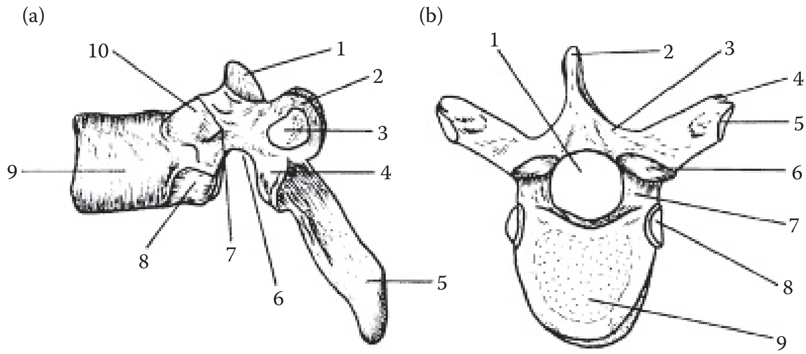


FIGURE 3.9 (a) Seventh thoracic vertebra (lateral view). 1. Superior articular process; 2. transverse process; 3. transverse costal facet; 4. inferior articular process; 5. spinous process; 6. inferior vertebral notch; 7. pedicle; 8. inferior costal facet; 9. vertebral body; 10. superior costal facet.

(b) Seventh thoracic vertebra (top view). 1. Vertebral foramen; 2. spinous process; 3. vertebral arch; 4. transverse process; 5. transverse costal facet; 6. superior articular process; 7. pedicle; 8. superior costal facet; 9. vertebral body (superior surface).

The vertebral column consists of 33 vertebrae: 7 cervical, 12 dorsal or thoracic, 5 lumbar, 5 sacral fused to form 1 bone, and 4 in the coccyx fused to form 1 bone. Not all vertebrae are identical; however, each of them represents the following characteristics or components: Spinous process (a posterior prominence), two vertebral arches, two transverse processes, two pedicles (root of vertebral arch), and vertebral foramen, body of the vertebra, two superior articulating facets, and two inferior articulating facets. Figure 3.9a and 3.9b shows a characteristic vertebra.

The vertebrae are interconnected by the intervertebral disc, which is elastic spongy disc containing about 80% water. The nucleus has a glycosaminoglycan matrix which is a combination of different substances especially glycoproteins, polysaccharides, and blood-group substances. The intervertebral disc is able to change its shape under pressure; it has no nerves or blood vessels from adulthood. The spinous processes of each vertebrae connected by interspinal ligaments.

The vertebral column has three major roles:

1. The protection of the spinal cord.
2. The static role in which the vertebral column supports the head and internal organs with its attachment of ligaments and serves the muscles to the thorax and extremities. The vertebral column serves

as a link between the upper and lower extremities and supports the weight of the torso, head, and upper extremities.

The vertebral column is not a rigid entity, it has sagittal curves. These curves are hereditary, however, they can be pathologic. Most evident are the thoracic curves, which have posterior convexities and lumbar curve which has a posterior concavity. When these curves are pathological, then the thoracic curve is called kyphosis and the lumbar curve called lordosis. The vertebral column has also a lateral curve and when it is pathologic named scoliosis. The combination of a lateral curvature with an anteroposterior lump of the spine is called kyphoscoliosis.

3. The biomechanics role: Transmission of force of the lower extremities to the upper extremities (echelon) of the body and mobility of the trunk and stability.

The vertebral column has the freedom of many types of movements, such as flexion (leaning the body forward), extension (leaning the body backward), lateral flexion (left or right), circumduction, and limited rotation. Rotation occurs most freely at the atlantoaxial joint (between the atlas and axis vertebra) and a little bit at the lumbar region.

There are some factors which influence the stability and mobility of the column. These are pressure between the intervertebral discs and sagittal curves influencing the vertebral column mobility. The greater the sagittal curves the more mobility is reduced. More freedom is available with thicker discs particularly at the lumbar level. Thickness and strength of the ligaments influences positively or negatively the stability and mobility of the vertebral column.

3.7.2 Articulations of the Vertebrae

The vertebrae articulations are classified as cartilaginous or amphiarthroses (having a slight mobility). The unification of the vertebrae is made through intervertebral discs. They have a biconvex and round shape which adheres to a vertebra on both parts of the disc. The thickness of these discs is between 3 mm at the cervical region, 5 mm at the thoracic region, and approximate 9 mm at the lumbar region. The intervertebral disc has two parts: The outer portion called the *annulus fibrosus* which is made up of conjunctive fibers and represents the larger portion of the disc. The center portion is much smaller, it is called the *nucleus pulposus;* it is elastic and has yellow color during adulthood.

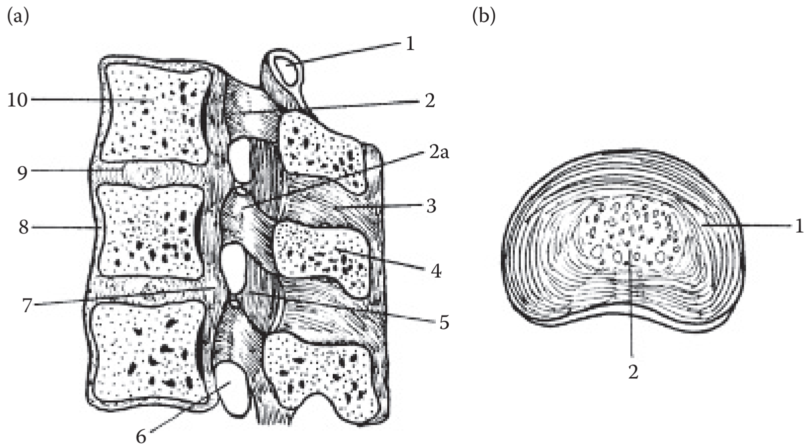


FIGURE 3.10 (a) Ligaments of the vertebral column (lumbar I, II, and III) sagittal section. 1. Superior articular process; 2. and 2a. pedicle; 3. interspinal ligament; 4. spinous process; 5. ligamentum flavum; 6. intervertebral foramen; 7. dorsal longitudinal ligament; 8. ventral longitudinal ligament; 9. intervertebral disc; 10. vertebral body.
(b) Intervertebral disc. 1. Annulus fibrosus; 2. nucleus pulposus.

Vertebrae have other articulations and connections between them with ligaments such as the ventral longitudinal ligament, which is a strong ligament especially in the lumbar area. There is also the dorsal longitudinal ligament and the ligamentum flavum. These three ligaments run from the axis to the sacrum. *Ligamentum nuchae* serves the cervical region, *ligamentum supraspinous* serves the thoracic and lumbar area, and *ligamentum interspinous* serves mostly the lumbar area and other areas. See Figure 3.10a and 3.10b which shows the ligaments of the vertebral column.

3.7.3 Muscles Operating the Vertebral Column (Dorsal Part)

This section will describe only those muscles which are directly connected to the vertebrae. *Musculus splenius capitis* is a thin but broad muscle which lies under the trapezius, rhomboideus, and serratus posterosuperior. *Insertion:* The origin of insertion is on the superior lateral nuchal line and spinous processes C7, T1, and T3. The distal insertion is on the mastoid process of the temporal bone.

Musculus splenius cervicis is also thin and narrow but it is a longer muscle than the splenius capitis. *Insertion:* Thoracic vertebrae (T3–T6) insert distally on the tip of the transverse processes of atlas, axis, and C3 bones. They are connected also to the interspinous ligaments.

Action: Both splenius muscles are extensors of the head when they contract bilaterally. If they contract unilaterally, then they act as flexors of the head and slight rotators at the same time. Innervation is given by the lower cervical nerves of the dorsal ramus. Musculus splenius capitis and splenius cervicis are shown in Figure 3.4b under Section 3.3, The Shoulder Complex.

Musculus erector spinae represents three different muscles, *musculus iliocostalis, longissimus,* and *spinalis*. These muscles adhere to three distinctive regions of the vertebral column. They occupy the costovertebral grooves excepting the iliocostalis muscle. They have a commune muscular mass on the sacrolumbar portion of the sacrum which is connected to fascia toracolumbaris. Also this commune muscular mass is connected to the spinous processes of the last lumbar vertebrae, the median ridge of the sacral bone, the posterior part of the sacrum, and on the posterosuperior iliac spine.

Musculus iliocostalis is in the *lumborum* region and its origin is on the thoracolumbar aponeurosis (dorsal part of the ribs). Distal insertion is on the last six ribs.

The *thoracis* region origin is also on the thoracolumbar aponeurosis. Distal insertion is on the posterior ribs of the thoracic vertebrae. The origin of the *cervicis* region is on the ribs 3–6 and the distal insertion is on the cervical transverse processes (C3–C7).

Musculus longissimus is closely attached to the vertebral column. The *thoracis* region origin emerges from the commune muscular mass with two fascicules for distal insertion. Distal insertion is on mastoid process and on the cervical and thoracic transverse processes. The *cervicis* region origin is on the first five thoracic transverse processes. Distal insertion is on cervical vertebrae (3–7). The *capitis* region origin is attached to cervical (C5–C7) and thoracic (T1–T5) vertebrae. It is distally inserted on the tip of the mastoid process.

Musculus spinalis attached medial is difficult to identify because its fascicule are mixed up with musculus longissimus. It has also three regions, *thoracis, cervicis,* and *capitis*. These three muscles act as extensors of the vertebral column.

Musculus transversospinalis represents three different muscles, *musculus semispinalis, multifidi,* and *rotatores*. *Musculus semispinalis* has three regions, *thoracis, cervicis,* and *capitis.* These three muscles have their origin on the thoracis region vertebrae. They are distally inserted between both nuchal lines of the cranium.

Musculus multifidi are present in the vertebral grooves from the sacrum to the axis bone. *Musculus rotatores* occupy the most profound region of

the transversospinal muscles and it is covered by the multifidi muscles. Rotatores represent three different muscles:

1. *Rotatores* have its origin on the transverse processes of all vertebrae. Distal insertion is on the spinous processes of all the vertebrae. It is an extensor of the vertebral column.

2. *Interspinales* have its origin on the spinous processes of the cervical, thoracal (T1, T2, T11, and T12), and lumbar vertebrae. Distal insertion is on the spinous processes of vertebrae (above origin). It is an extensor of the vertebral column.

3. *Intertransversarii* have its origin on the transverse processes of the cervical, thoracic (T10–T12), and lumbar vertebrae. Distal

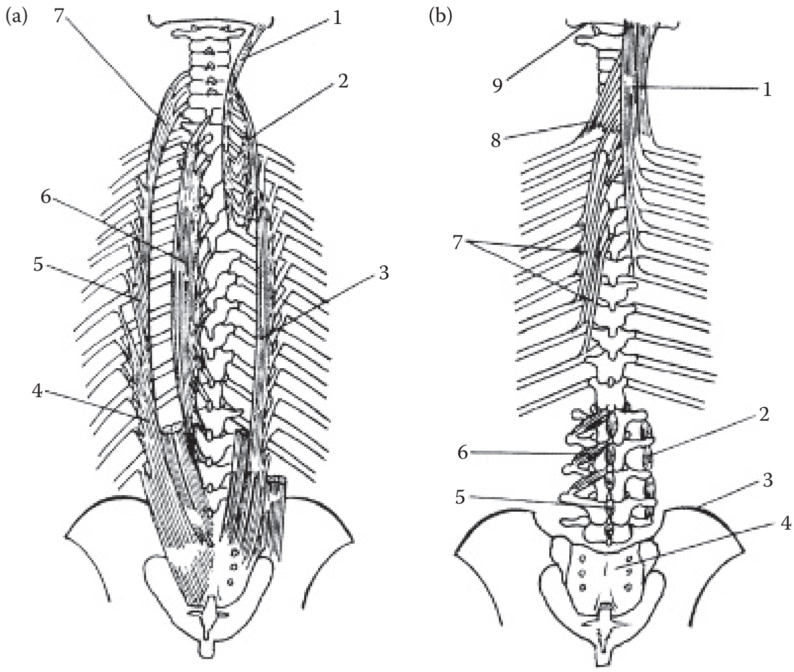


FIGURE 3.11 (a) Muscles connected to the vertebral column and/or ribs (dorsal part of the body). 1. Longissimus capitis; 2. longissimus cervicis; 3. longissimus thoracis; 4. iliocostalis lumborum; 5. iliocostalis thoracis; 6. spinalis thoracis; 7. iliocostalis cervicis.

(b) Deep dorsal muscles of the vertebral column. 1. Semispinalis capitis; 2. intertransversari; 3. pelvis; 4. sacrum; 5. interspinalis; 6. rotatores; 7. semispinalis thoracis; 8. semispinalis cervicis; 9. nuchal line.

insertion is on the transverse processes of vertebrae (above origin). It is an extensor of the vertebral column and unilaterally a flexor. Figure 3.11a and 3.11b shows some of the dorsal muscles of the body connected to the spine and/or ribs which were described earlier.

3.7.4 Muscles of the Back

Large muscles of the back include the following: *Musculus trapezius*, *latissimus dorsi*, *levator scapulae*, *rhomboideus minor* and *major*, *serratus posterior superior* and *inferior*, *splenius*, *infraspinatus*, and *supraspinatus*; however, only the *latissimus dorsi*, *rhomboideus minor/major*, and both *serratus* muscles will be described. The rest of the muscles have been described in Section 3.3, The Shoulder Complex.

Musculus latissimus dorsi is the broadest muscle of the back. This muscle is covered directly by the skin of the back. It has a triangular shape and occupies the posteroinferior part of the trunk. *Insertion:* The origin of this muscle is on the last three or four ribs. This muscle fuses with the thoracolumbaris fascia which inserts at the lower six thoracic processes and on the sacroiliac portion of the iliac crest. Some fibers have the origin at the inferior angle of the scapula. The fibers converge toward axilla, twist and unite on the anterior portion of the teres major and distally insert on the intertubercular groove of the humerus.

Action: Different actions depend on the location of their “fixed point” for action. (The fixed point refers to those insertions/sides of the muscle which are considered immovable during a muscular action). When the fixed point is on the vertebral column then the latissimus dorsi is an extensor, internal rotator, and adductor of the humerus. When the fixed point is on the humerus then the latissimus dorsi elevates the thorax during inspiration. Innervation is given by the thoracodorsal nerve from the brachial plexus.

Musculus rhomboideus minor and *rhomboideus major* are identical muscles and they stick together lengthwise. Rhomboideus major is wider than rhomboideus minor. *Insertions:* Rhomboideus minor has its origin on spinous processes of C7 and T1 vertebrae. Rhomboideus major has its origin on spinous processes of T2–T5 vertebrae. Rhomboideus minor distal insertion is on the root of the spine of the scapula (medial side). Rhomboideus major distal insertion is on the vertebral border of the scapula from the root of the spine to the inferior angle.

Action: Both muscles act as retractors and downward rotators of the scapula. Innervation is given from the cervical plexus through the collateral dorsal branch of the brachial plexus.

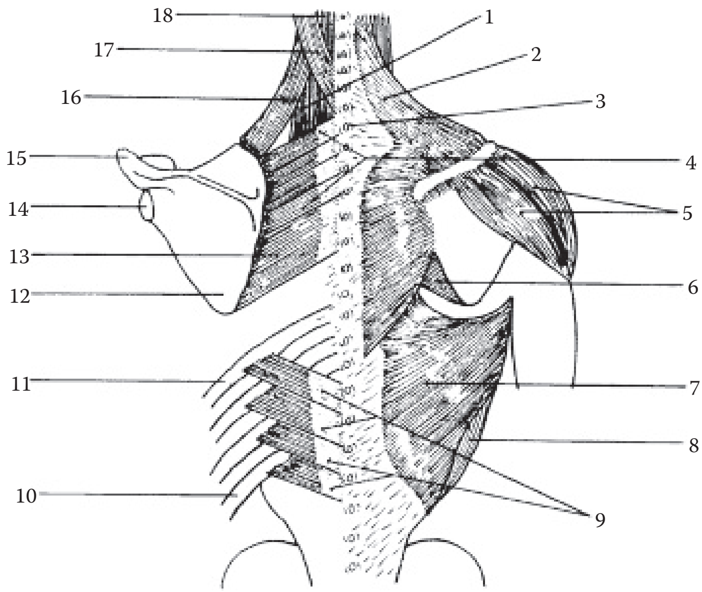


FIGURE 3.12 Muscles of the back. 1. Scalenus posterior; 2. trapezius; 3. 7th cervical vertebra (spinous process); 4. serratus posterior superior; 5. deltoideus; 6. rhomboideus major; 7. latissimus dorsi; 8. obliquus externus abdominis; 9. serratus posterior inferior; 10. the 12th floating rib; 11. the 9th (false) rib; 12. scapulae; 13. rhomboideus major; 14. glenoid fossa; 15. acromion of scapulae; 16. levator scapulae; 17. splenius capitis; 18. semispinalis capitis.

Musculus serratus posterior superior is a thin muscle having four fascicules. It is covered by the rhomboideus muscle. *Insertion:* The origin is on the spinous processes of C7–T3. Distal insertion is on the superior borders of 2–5 ribs. *Action:* Helps during inspiration by elevating the ribs. Innervation is assured by intercostal nerves.

Musculus serratus posterior inferior is a broader muscle than the serratus posterior superior. It is covered by the latissimus dorsi. *Insertion:* The origin is on the spinous processes T11, T12, and L1–3 vertebrae. Distal insertion is on the inferior borders of the last four ribs. *Action:* During expiration this muscle helps to draw the ribs outward and downward, enlarging the thorax. Innervation is assured by intercostal nerves 9–12. Figure 3.12 shows schematically some of the large muscles of the back described above.

3.8 THE THORACIC REGION

The thoracic region can be divided into subregions, the upper thoracic region, and the lower thoracic or abdominal region.

3.8.1 Upper Thoracic Region

The muscles that are found under the clavicle bone will now be described. Connected to the clavicle and/or the sternum or to the ribs, they are the *musculus pectoralis major, pectoralis minor, subclavius,* and *serratus anterior*. These muscles, except the musculus subclavius, are sometimes referred to as part of the shoulder complex; however, the author will describe these muscles in this section.

Musculus pectoralis major is a broad muscle and it has three fasciculi. *Insertion:* Fasciculus superior (pars clavicularis) origin is on the anterior medial half of the clavicle. Fasciculus medial (pars sternocostalis) origin is on the anterior part of the sternum and on the cartilages of the first six ribs. Fasciculus abdominal (pars abdominalis) is connected to the vagina (sheat) musculi recti abdominis (the upper part or first section of the muscle).

These three fascicules unite with a single tendon (broad, ~5 cm) and distally insert in front and under the greater tubercle of the humerus and touching also the bicipital groove of the humerus. The distal insertion in fact is prolonged at the shoulder ligament capsules and the brachial fasciculus.

Action: It is an adductor of the humerus especially when the arm is in a horizontal position. It is an internal rotator of humerus and helps with inspiration. Innervation is given from the brachial plexus of lateral pectoral nerve.

Musculus pectoralis minor is a smaller muscle than the pectoralis major and lies underneath. *Insertion:* The origin has three portions and is inserted on the anterolateral surfaces of the third, fourth, and fifth ribs a little bit further from the costal cartilages. Distal insertion is on the coracoid process of the scapula on the medial margin of the superior surface.

Connections: The posterior portion covers medially the ribs, intercostal spaces, and serratus anterior. The superomedial margin is separated by the subclavius muscle and a space occupied by the clavicular and pectoral fascia.

Action: Depression, protraction and downward rotation of scapula. Innervation is given by medial and lateral pectoral nerves from the brachial plexus.

Musculus subclavius is a long and thin muscle. *Insertion:* Its origin is on the first rib costocartilage junction and the distal insertion is on the inferior and middle surface of the clavicle. *Action:* This muscle descends the clavicle and shoulder. It protects the brachial plexus and subclavicular blood vessels from any hard contact by the clavicle. Innervation is given by the subclavius nerve from the brachial plexus.

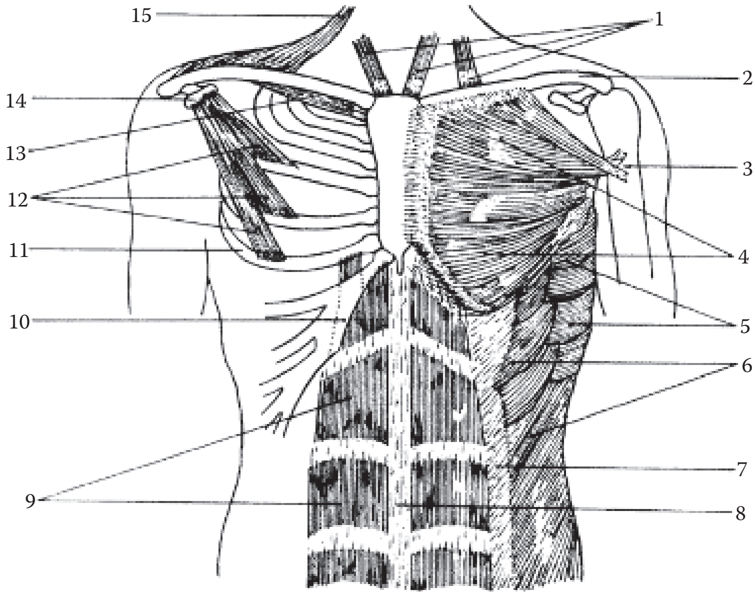


FIGURE 3.13 Muscles of the upper thoracic region. 1. Sternocleidomastoid; 2. clavicle; 3. pectoralis major insertion; 4. pectoralis major; 5. serratus anterior; 6. obliquus externus; 7. aponeurosis of obliquus externus; 8. linea alba; 9. rectus abdominis; 10. dotted portion covers the rectus abdominis; 11. the fifth rib; 12. pectoralis minor; 13. subclavius; 14. coracoid process; 15. trapezius.

Musculus serratus anterior occupies the largest part anterolateral of the thorax. *Insertion:* The origin has three muscular sections. They extend from the outer surface of the upper eight ribs. The distal insertion for all three sections is on the vertebral border (anterior surface and inferior border) of the scapula.

Connections: The deep portion of this muscle is fixed to the participating ribs and intercostal space. The top portion is in contact with the axilla. *Action:* Stabilizes the scapula on the thorax. It is a protractor and upward rotator of the scapula. It participates in inspiration with the top and bottom sections and is an expiratory with the middle section of the muscle. Innervation is assured by the long thoracic nerve from the brachial plexus. Figure 3.13 shows the muscles of the upper thoracic region (superficial layer) described above.

3.8.2 The Axillary Region

It is an important region of the human body. At this region, many muscles criss-cross and cover different parts of the axilla, such as the musculus

pectoralis major and minor, subclavius, latissimus dorsi, teres major, and serratus anterior. The axilla covers other important anatomical parts such as the ulnar nerve, axillary artery, axillary vein, long thoracic nerve, thoracodorsal nerve, and other smaller nerves and veins.

3.8.3 Fasciae of the Antero-Lateral Region of the Thorax

These fasciae are fibrous membranes which cover, support, and separate muscles. Fascia may be a superficial or subcutaneous matter which allows free movement of the skin, or it may be a deep, enveloping and binding sheet of connective tissue over the muscles. Here are several fasciae:

Fascia pectoralis covers clavicle and sternum; however, it is separated from the skin by a lax tissue. Within this lax tissue is the female mammary gland. Fascia pectoralis has two margins: superolateral, covering deltoideus and pectoralis muscles and inferolateral margin of which one covers the posterior part and axillary part of the muscle.

Fascia axillaris is a continuation of the fascia pectoralis. *Fascia subclavius* totally covers the subclavius muscle. *Fascia clavipectoralis* covers pectoralis minor.

3.8.4 Muscles of the Thorax

There are four major muscles which intervene in the respiration process. *Musculi intercostales* fill the space between ribs uniting them together. There are three intercostal muscles. *Musculus intercostales externi* insert originally or distally between two ribs. However, these muscles insert a little bit higher than the external margin of the ribs. *Musculi intercostales interni* insert originally and distally exact on the internal margin of two ribs. *Musculi intercostales intimi* are found deeply embedded in the internal intercostals.

Action: Intercostales externi are inspiratory, they ascend the ribs. *Intercostales interni* are expiratory, they descend the ribs. Innervation is given by the anterior branch of thoracic spinal nerves.

Musculi levatores costarum include 12 pairs of thin muscles on each side of the vertebra. *Insertion:* The origin is on the tip of the transverse processes of C7–T11. Their distal insertion is on the rib below. *Action:* Inspirator by raising the ribs during inspiration. Innervation is given by thoracic spinal nerves (anterior rami).

Musculus serratus posterior superior and *serratus posterior inferior* muscles have been described in Section 3.7.4, “Muscles of the Back.”

Musculi subcostales are thin muscles found inside the thorax between the pleura and the intercostales intern. These muscles have no functional value.

Musculus transversus thoracis is found at the deep portion of the sternocostal region which has five muscular fascicul. It divides nerves and intercostal vessels from the pleura (serous membrane) of the lung. It is somewhat homologous with musculus transversus abdominis. *Insertion:* Origin is inserted on the dorsal part of the xiphoid process and sternum. Distal insertion is on the inferior margins of costal cartilage 2–6. Fasciculi have an oblique direction continuing with musculus transversus abdominis. It has a reduced function in respiration. Innervation is given by intercostal nerves 2–6. This subchapter is not illustrated, however, the muscles serratus posterior superior and posterior inferior are shown in Figure 3.12.

3.8.5 Lower Thoracic Region (Muscles of the Abdomen)

Musculi abdominis can be divided into four regions: *Anterolateral, posterior* or *iliolumbar, superior* or *diaphragm*, and *inferior* or *perineal.* These muscles will be described irrespective of their regions and are represented by Figure 3.14.

Musculus rectus abdominis is a long muscular band from anteroinferior part of the thorax ending at the pubis bone. *Insertion:* The original insertion is on the pubic symphysis with one single tendon. Distal insertion is on the costal cartilages of ribs 5, 6, 7, and xiphoid process. The rectus abdominis is fragmented with three to four transversal tendinous intersections. It is also divided vertically in two parts by the linea alba which was described earlier. Rectus abdominis is the strongest abdominal muscle and forms a strong fibrous region of traction and unification with the rest of the abdominal muscles.

Action: Flexor of the trunk and also expirator. Innervation is given by intercostal nerves T7–T12.

Musculus pyramidalis has no functional value. Original insertion is on the pubis. Distally inserted at the end of the linea alba.

Musculus obliquus externus abdominis is superficial and extends from the lateral muscles of the abdomen. This muscle has two parts: muscular and aponeurotic. *Insertion:* The origin is on the external portion of the ribs (5–12). It is connected to the serratus anterior and latissimus dorsi. From the origin, the muscle fibers are straightened obliquely down and end in two portions. Posterior fasciculi from the last two ribs have almost complete vertical direction and distally insert on anterior iliac crest.

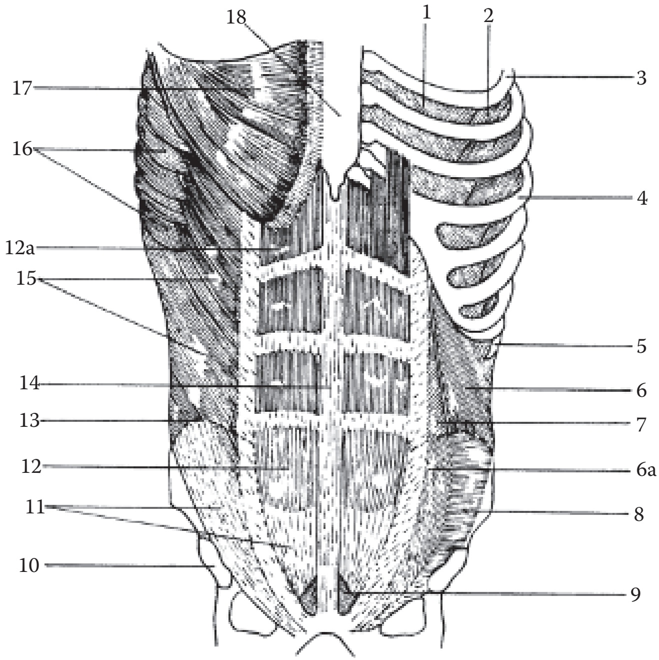


FIGURE 3.14 Muscles of the lower thoracic region. 1. Intercostales interni; 2. intercostales externi; 3. third rib; 4. sixth rib; 5. eleventh rib; 6. and 6a. obliquus internus abdominis; 7. obliquus externus abdominis; 8. transversus abdominis; 9. pyramidalis; 10. acetabulum; 11. aponeurosis; 12. and 12a. rectus abdominis; 13. top of the iliac crest; 14. linea alba (exactly in the middle line of the rectus abdominis, from the top to the bottom insertion); 15. obliquus externus abdominis; 16. serratus anterior; 17. pectoralis major; 18. sternum.

Number 13 represents the tip of the iliac crest where the muscles obliquus externus, internus, and transversus abdominis are inserted. These three muscles have other insertions which have been described earlier.

The rest of the fasciculi form the thin band of rectus abdominis. Other small fasciculi insert on the pubis. It is important to mention that between the abdomen and thigh there is the inguinal ligament. Obliquus externus has many connections, but these will not be described here. Innervation is given by intercostal nerves T7–T12 and L1 which is the ilioinguinal nerve.

Musculus obliquus internus abdominis is a wide muscle situated under obliquus externus abdominis. Its fibers have the opposite direction to those of the obliquus externus.

Insertion: The origin has three bundles of muscles: The posterior fasciculi inserted on toracolumbar fascia together with musculus latissimus

dorsi; the middle fasciculi inserted on iliac crest; and the anterior fasciculi inserted on the inguinal ligament. Distally they insert on costal cartilages of ribs 9–12 through the linea alba.

Action: When the muscles contract bilaterally then flexion of the trunk results. Obliquus externus and rectus abdominis act as a compressor of the abdominal contents. Unilaterally the trunk executes flexion and rotation on the side of the muscle contraction.

Musculus transversus abdominis is a wide muscle situated deeply between those lateral abdominal muscles. This muscle has two parts: one is muscular; the other is aponeurotic and has also two parts (anterior and posterior).

Insertion: The origin is taken from the upper part downward: (a) from the internal and median part of the last six costal cartilages, (b) from thoracolumbar aponeurosis, (c) through the iliac crest, (d) and finishing at the first third of the inguinal ligament. Distal insertion has many portions but only two will be mentioned, linea alba and the pubis bone. This muscle is covered by oblique interns and its deepest part has connection with the peritoneum.

Action: Compresses the internal organs in the abdomen. Innervations are assured by intercostal nerves of T7–T12 and L1. As an observation about muscles *obliquus externus abdominis, obliquus internus abdominis,* and *transversus abdominis* they all have insertions on the iliac crest. See Figure 3.14.

3.9 THE HIP GIRDLE

The hip or pelvic girdle/region refers to the same area. The hip girdle is represented by a large and heavy bone unit called the pelvis or "os" (bone) coxa (hip). In any martial art, the hip region is of utmost importance. The hip is the guiding force for a majority of different techniques, because it is the strongest part of the body not only because of its bony structure, but also because of its muscular conformation.

The pelvis is a rigid massive bony basin connecting the trunk and the lower extremities. The pelvis is made up of three different and distinctive bones: The upper portion made up of two bones named *ilium*, the middle part which is somehow a lower part is the *pubis,* and the bottom portion is the *ischium*. The two ilium bones are united by the *sacrum* bone and the pubis bone is united by pubic symphysis. The total unification (fusion) of these bones occurs at the time of puberty. At the lower extremity of the sacrum is a tiny bone named *coccyx* or tailbone.

The ilium is the largest and heaviest bone in the pelvic region. The hip girdle assures stability and mobility for the vertebral column. The hip has a limited degree of freedom of movement. The movements are flexion and extension in the sagittal plane and abduction and adduction in the frontal plane. Medial and lateral rotation, around the longitudinal axis of the body and lateral flexion/inclination is to the right and to the left. These movements are related to the coxofemoral articulation.

The hip girdle joints should be classified into two categories:

1. *Ligamentous reinforcers* for the hip girdle. Some of them are *Sacroiliac* ligament (ventral and dorsal) which unites the ilium and the sacral bone; *Iliolumbar* ligament unites the ilium and the lumbar region of the vertebral column; *Sacrococcygeal* ligament; *sacrolumbar* ligament; interpubian disc; *ischiosacral* ligament; and *sacrotuberous* ligament, and so on. These ligaments are reinforcers of the pelvic bones. They have no or extremely limited possibilities of movement. Figure 3.15a shows the pelvis and the most important ligamentous reinforcers (joints of the pelvis bone).

2. *Coxofemoral articulations* (related to hip and femur bones). In sport or fitness, the experts usually speak about the coxofemoral articulations only. The hip bone and the femur bone articulate through their surfaces: The head of the femur and the acetabulum of the coxa bone are an example. The acetabulum is a hollow space where the head of the femur communicates through sliding and rotating. Figure 3.15b shows the coxofemoral articulations.

The central portion of the acetabulum is the acetabular fossa which is nonarticular and contains a fatty padding that is filled with synovial fluid. The entire socket is surrounded and deepened into a fibrous and cartilaginous ring, called the acetabulum labrum.

Here are the coxofemoral articulations: *Iliofemoral* ligament is the most powerful ligament of the coxofemoral joint. This ligament has the shape of a fan and is very large. This ligament can support a 350–500 kilogram mass. *Insertion:* The origin is on anteroinferior iliac spine. The distal insertion is on the intertrochanteric line of the anteriomedial surface of the femur. This line runs obliquely from the greater trochanter to the lesser trochanter.

The iliofemoral ligament has a limited action on the hip extension, external rotation, and adduction, while it firmly supports the femur head into the acetabulum.

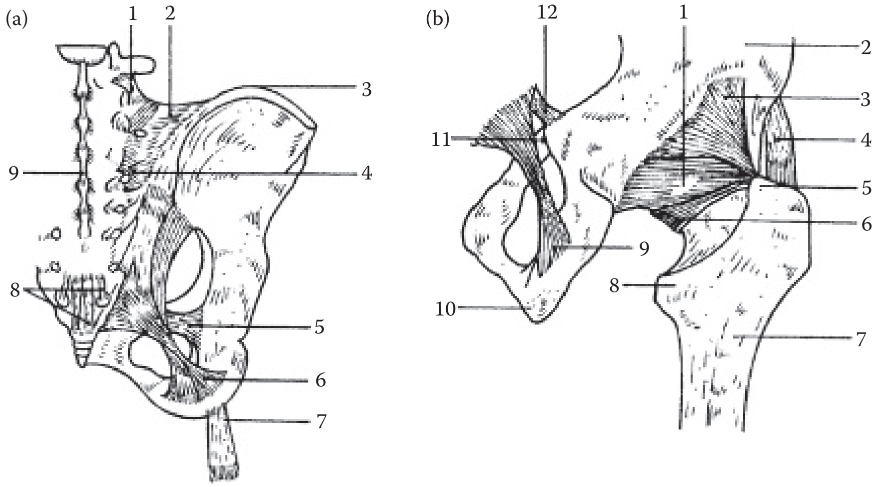


FIGURE 3.15 (a) Ligaments of the pelvis bone (reinforcers) (posterior view). 1. Intertransverse ligament; 2. iliolumbar ligament; 3. iliac crest; 4. sacroiliac ligament; 5. sacrospinous ligament; 6. sacrotuberous ligament; 7. biceps femoris (origin insertion); 8. sacrococcygeal ligament; 9. supraspinous ligament.

(b) Coxofemoral articulations (posterior view). 1. Ischiofemoral ligament; 2. bone of ilium; 3. iliofemoral ligament; 4. rectus femoris ligament; 5. greater trochanter; 6. zona orbicularis; 7. femur; 8. lesser trochanter; 9. sacrotuberous ligament; 10. ischial tuberosity; 11. ischial spine; 12. sacrospinous ligament.

Pubofemoral ligament is also situated on the anterior part of the coxofemoral ligament. *Insertion:* The origin extends from the superior ramus of the pubis. The distal insertion is on the hip capsule near the neck of the femur. It acts to prevent excessive extension and abduction of the thigh.

Ischiofemoral ligament is situated on the posteroinferior part of the ischium. *Insertion:* The origin is on the ischium behind and under the acetabulum. *Caput femoral* (head of the femur) ligament is an intra-articular fibrous thin blade with a triangular shape. This ligament has the following importance: (a) contains nutritive vessels and has the most important role during osteogenesis, (b) its little movements contribute to spreading the synovial secretion on the articular surface. Figure 3.15b shows the coxofemoral articulations.

3.9.1 Muscles of the Pelvis

Muscles of the pelvis are directly connected to the vertebral column and to the femur. Connection to the vertebral column has the importance

of maintaining the body's stability, while the connection to the femur assures the different types of locomotion using the lower extremities, particularly the legs. This connection is also important for the transmission of force to the lower extremities.

An example of this is the reverse punch *(Gyaku-zuki)*. In this movement, the bundle of the hip muscles is extremely important because it is the first segment of the body that enters into execution of the punch. The reverse punch muscular action will be described in detail later.

The agglomerated muscles of the pelvis can deliver a great force, which is directed to the coxofemoral articulation. The majority of these muscles are voluminous, short, and strong. It is well known in mechanics that a short muscle mostly delivers force while a long muscle mostly delivers speed.

3.9.2 Anterior Muscles of the Pelvis

In this category, muscles are grouped *anteriorly* and *interiorly:* (1) *Musculus psoas major* and *iliacus* are two muscles usually referred to as the *musculus iliopsoas* because of their common action and insertion. (2) *Musculus psoas minor* is a rudimentary muscle and for about 50% of the human population it is missing. It is situated in front of the psoas major. This muscle will not be described. These two muscles are shown in Figure 3.16a.

Musculus psoas major is a long muscle and has the shape of a fusiform. *Insertion:* The origin is on the last thoracic vertebra (T12) and the first four lumbar vertebrae. Distal insertion is on the lesser trochanter of the femur. *Action:* Psoas major with iliacus is the strongest hip flexor. If the thighs are fixed it has an important role during regular sit-up execution.

Musculus iliacus has a wide and triangular shape. *Insertion:* The origin is on the iliac fossa. The distal insertion is on the lesser trochanter of the femur together with the psoas major. *Action:* Its action is similar to psoas major. It is a hip flexor. Iliacus acts directly and exclusively on the coxofemoral articulation. Innervation of psoas major and iliacus is assured by the femoral nerve (L2, 3, 4).

Iliopsoas has many muscular and other connections. At the abdomen level it is in connection with the psoas minor and with different abdominal organs, such as the kidneys and their vessels, the ureter, the spermatic or ovarian vessels, and the ascending and descending colons.

Iliopsoas has the principal role as flexor of the pelvis; however, it also intervenes in locomotion and regulates the stride of humans. When iliopsoas is paralyzed, walking is almost impossible. If both femurs are fixed, then iliopsoas acts as a stabilizer for static positions.

3.9.3 Posterior Muscles of the Pelvis

In this category, muscles are grouped *posteriorly* and *exteriorly:* There are a total of 10 muscles. *Musculus gluteus maximus*, *gluteus medius*, *gluteus minimus*, *piriformis*, *gemellus superior*, *gemellus inferior*, *obturator externus*, *obturator internus*, *quadratus femoris*, *quadratus lumborum*. One muscle is grouped laterally. This is the *tensor fasciae latae*, which will be described under Section 3.10, The Thigh.

Musculus gluteus maximus is the most superficial and the most voluminous muscle of the pelvis and at the same time is one of the most powerful muscles of the human body. The bulk of the entire muscle is formed with thick fasciculi which run parallel to and are divided by aponeuroses. *Insertion:* The origin has three distinctive segments. 1. The gluteal portion is on the superior and posterior surface of the ilium 2. Sacrotuberous ligament which is related to sacrum and coccyx 3. Thoracolombar fascia. Distal insertion on the gluteal tuberosity of the femur then goes down through the iliotobial tract and continues to the lateral condyle of the tibia.

Action: The principal action of the gluteus maximus is extensor of the thigh. It is also a lateral rotator and an adductor of the thigh. Innervations are given by inferior gluteal nerve (L5, S1, and S2).

Musculus gluteus medius is a powerful triangular-shaped muscle with the tip of the triangle oriented downward. In fact, this muscle with gluteus minimus is situated laterally and not dorsally. It is covered by gluteus maximus and by *fascia glutea* which is part of *tensor fasciae latae*. *Insertion:* The origin is on the upper and outer surface of the ilium bone under the iliac crest between the posterior gluteal line and the anterior gluteal line. Distal insertion is on the greater trochanter of the femur. *Action:* It is an abductor of the hip and medial rotator of the femur (anterior fibers). It can also assist in the flexion of the hip. Innervations are given by superior gluteal nerve (L4, 5, and S1).

Connections: Gluteus medius covers entirely the bony field of the ilium, ischium, and gluteus minimus. The posterior margin is connected to the piriformis muscle, and is anteriorly covered by tensor fasciae latae. Trochanteric bursa of gluteus medius muscle facilitates the gliding process of its tendon on the greater trochanter.

Musculus gluteus minimus is smaller than gluteus medius and also has a triangular shape. *Insertion:* The origin is between middle and inferior gluteal lines. Distal insertion is on the greater trochanter of the femur. Innervation is given by the superior gluteal nerve. *Action:* It is an abductor and medial rotator of the femur.

Musculus piriformis has a triangular shape with the base oriented toward the sacrum. *Insertion:* The origin is on the anterior surface of the sacrum. Distal insertion is on the top of the greater trochanter of the femur. *Action:* Rotator of the hip, abductor of the femur when the hip is fixed and facilitates holding the femur head in the acetabulum.

Musculus gemellus superior and *gemellus inferior* are two thin muscles. *Insertion:* Gemellus superior has its origin on the external surface of the ischial spine. Gemellus inferior has its origin on the upper margin of the ischial tuberosity. Both gemelli converge toward the greater trochanter of the femur where they are distally inserted. The tendon of the obturator internus is between the two gemellus muscles. *Action:* Both gemelli working together with the obturator internus. Innervation is assured for each gemellus by a separate branch from the sacral plexus.

Musculus obturator externus lays under the gemellus inferior. *Insertion:* The origin is on the obturator foramen and ischium. Distal insertion is on the trochanteric fossa of the femur. Obturator externus lies deeply in the pelvis and is covered by the iliopsoas, pectineus, and quadratus femoris. *Action:* It is a lateral rotator of the femur. It also has another and more important role contributing to the stability of the femur head in the acetabulum of the coxal bone. Innervation is assured from the sacral plexus.

Musculus obturator internus have a strong association to both gemelli muscles. *Insertion:* The origin is on the inner surface of the pelvis bone (obturator membrane) and on the peripheral margin of the obturator foramen. Another origin insertion is on the inner surface of the ischium, pubis, and ilium. The origin with its connective fascia covers a large part of the ischium. *Action:* It is a lateral rotator together with both gemelli muscles. Innervation is assured from the sacral plexus branches.

Musculus quadratus femoris is a wide, but short rectangular muscle. *Insertion:* The origin is on the ischial tuberosity and is distally inserted on and below the intertrochanteric crest. *Action:* Lateral rotator of the femur. Innervation is assured from the sacral plexus branches.

Musculus quadratus lumborum represents the area of the posterior abdominal wall minus the posterior muscles of the pelvis. This muscle has more fiber segments at the distal insertion. *Insertion:* The origin is on the dorsal part of the iliac crest and is distally inserted on the 12th rib (medial part) and continues with four distal insertions on the transverse processes of the lumbar vertebrae 1–4. *Action:* It is a lateral flexor of the trunk and helps to extend the lumbar vertebral column. Bilaterally, it gives a strong stability to the trunk. Posterior muscles of the pelvis are represented by Figure 3.16b.

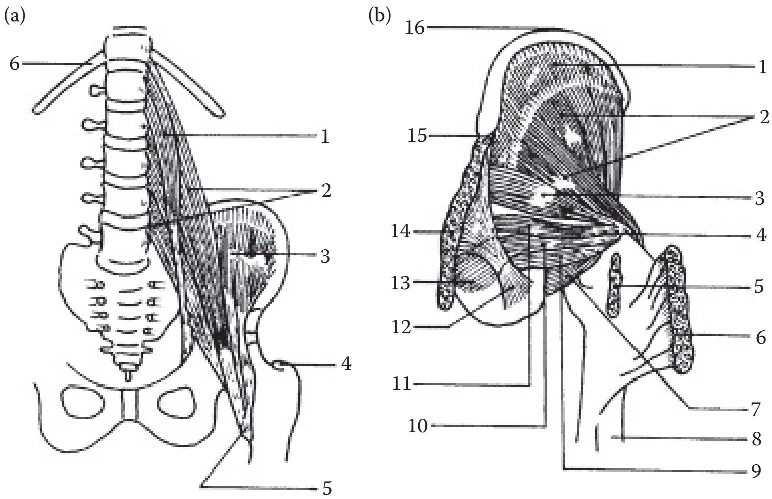


FIGURE 3.16 (a) Ventral muscles of the pelvis. 1. Psoas minor; 2. psoas major; 3. iliacus; 4. greater trochanter; 5. lesser trochanter; 6. 12th (floating) rib.

(b) Dorsal muscles of the pelvis. (Deep and superficial muscles.) 1. Gluteus medius; 2. gluteus minimus; 3. piriformis; 4. greater trochanter; 5. quadratus femoris (sectioned); 6. gluteus maximus (sectioned); 7. obturator externus; 8. femur; 9. gemellus inferior; 10 and 13. obturator internus; 11. gemellus superior; 12. sacrotuberous ligament; 14. gluteus maximus sectioned; 15. gluteus maximus insertion on the ilium; 16. iliac crest.

3.9.4 Muscles of the Pelvis and Their Role

It must be specified that the pelvis has the role of an intermediary segment belonging to the trunk and inferior limbs. The pelvis' biomechanical key role is to serve as a mobile muscle-stuffed bucket. The pelvis rotates and turns in different directions while connected with the two femur heads and also sustains verticality of the vertebral column for the upper parts of the body.

Muscles of the pelvis and some muscles of the thigh can execute the following actions: 1. pendulant movement of the thigh in relation to the trunk, 2. movements of the trunk in relation to the fixed thigh, 3. through static contraction unites and balances the two upper and lower segments (trunk and legs).

A movement of the lower limbs when the pelvis is fixed is indispensable for locomotion, but the primary function of the muscles around the coxofemoral articulation is the pivot movement of the pelvis on the two femur heads.

Movements of the pelvis related to the coxofemoral articulations are flexion, extension, abduction, and adduction plus internal and external rotation. It must be mentioned that some muscles have a *biarticular* role, for example, *Sartorius*, which is an abductor and lateral rotator of the hip joint is also a flexor of the pelvis. Muscles which act as *monoarticular* are less than *biarticular* joints. The most important muscles and their actions follow.

The principal flexors are *iliopsoas*, *rectus femoris*, and *tensor fasciae latae* which flexes the pelvis when the thigh is flexed a little bit and the last flexor is the *sartorius*. The secondary flexors are *gluteus medius* and *minimus*. The primary nerve for the movement of flexion is the femoral nerve. The secondary nerves are gluteal superior and obturator nerve.

The extensors contrary to the flexors have the primary role in maintaining the erected position and counter gravitational position. The extensor muscles can stabilize the coxofemoral articulation in any intermediary position of the flexion. The principal extensors are *gluteus maximus*, *biceps femoris* (long head), *semitendinosus, semimembranosus*, and *adductor magnus* (posterior head). Secondary extensors with more or less help are *piriformis, obturator internus*, both *gemellus*, *obturator externus, adductor brevis, gracilis*, and *quadratus femoris*. The primary nerves for the movement of extension are the gluteal superior and inferior. The secondary nerve is the obturator.

Abductors and adductors have a primary role in pivoting the pelvis in the frontal plan when the body weight is supported on a single leg. The principal abductors are *gluteus medius and minimus, tensor fasciae latae,* and *sartorius.* Adductors are more powerful than abductors. The principal adductors are *adductor magnus, longus* and *brevis, gracilis* and *pectineus*. Secondary adductors are *obturator externus, internus*, and *sartorius*. The primary nerve for the movement of adduction is the obturator nerve. Some of the lateral rotators of the pelvis are *obturator internus, quadratus femoris,* and *gemellus superior* and *inferior.* Some of the medial rotators are *gluteus medius* and *minimus* and *tensor fasciae latae*.

3.10 THE THIGH

In the previous chapter, the muscles were described as extensors/flexors, abductors/adductors, and rotators. These descriptions were mostly related to the hip action. Muscles of the thigh will be described by their regions, such as the ventral, medial, and dorsal region. Their actions, for example, the extensors/flexors and abductors/adductors are related to the knee and

the leg. Rotators are excluded from here; they are related to the action of the pelvis. Muscles of the thigh are represented by Figure 3.17.

3.10.1 Ventral Muscles of the Thigh (Extensors)

Musculus sartorius and *quadriceps femoris* which include four muscles: *rectus femoris*, *vastus lateralis*, *vastus medialis*, and *vastus intermedius*. These muscles have the role of extending the leg for the most part.

Musculus sartorius is the longest muscle of the human body. It is ~50 cm long and it is easily palpable. It extends from the pelvis to the leg diagonally and passes through two articulations. *Insertion:* The origin is on the anterior superior iliac spine. Its facsiculi are parallel and it descends medially forming a boundary for the vastus medialis and rectus femoris. Distal insertion is on the upper medial shaft of the tibia bone.

Connections: The upper part of this muscle has contact with the skin; the profound portion of the sartorius has contact with rectus femoris, vastus medialis, and the adductor muscles. The superior portion of the sartorius is in connection with gluteus medius, tensor fasciae latae, and inguinal ligament. *Action:* It is a biarticular muscle and a flexor of the femur on the pelvis. It is also a weak lateral rotator and abductor of the thigh. The sartorius muscle helps with the cross-legged seated position. Innervation is given by the femoral nerve (L2 and L3).

Musculus quadriceps femoris includes four muscles which originate on the pelvis, and they distally insert on the tibial tuberosity via the patellar ligament. The middle portion of the quadriceps is occupied by two muscles: Rectus femoris and under this muscle is the vastus intermedius.

Musculus rectus femoris occupies the top portion of the quadriceps femoris which has two tendons of origin. *Insertion:* The origin of the reflected or (posterior) head tendon is on the ilium at the upper rim of acetabulum. The origin of the direct or (anterior) head tendon is on the anteroinferior iliac spine. Distal insertion passes over the patella and inserts on the tibial tuberosity. Rectus femoris is a bipennate muscle with a considerable muscular force having a biarticular role. *Action:* It is a knee extensor and hip flexor (evident in a karate kick). Innervation is given by femoral nerve (L2, 3, 4).

Musculus vastus lateralis is the most voluminous muscle and occupies the lateral part of the quadriceps femoris. *Insertion:* The origin is on the greater trochanter and lateral part of the linea aspera of the posterior part of the femur. Distal insertion has an aponeurosis tissue. The muscular fascicules end in a common tendon with the rest of the vastus medialis and

intermedius inserting on the tibial tuberosity. *Action:* It is a knee extensor. Innervation is assured by the femoral nerve (L2, 3, 4).

Musculus vastus medialis is most voluminous muscle at the knee. Interestingly, this muscle can be seen on the ventral part of the thigh; however, it extends on the posterior part of the femur too. *Insertion:* The origin is on the distal one-half of the intertrochanteric line also medial part of the linea aspera and medial supracondylar line. Distal insertion is on the medial margin of the patella, tibial tuberosity via patellar ligament also at the medial condyle of the tibia. *Action:* Extensor of the knee joint. Innervations' is given by femoral nerve (L2, 3, 4).

Musculus vastus intermedius occupies the deepest part of the quadriceps femoris. This muscle is situated directly on the femur having a membranous tendon on its anterior surface allowing a gliding movement between itself and rectus femoris. *Insertion:* The origin is on the anteriolateral shaft of the femur bone. It also occupies the lower half of the linea aspera and lateral supracondylar line. Distal insertion is on tuberosity of the tibia via the patellar ligament. *Action:* Extension of the knee. Innervations are given by femoral nerve (L2, 3, 4).

3.10.2 Observation about Quadriceps Femoris

Quadriceps femoris has the primary role of action as the extensor of the knee. Only rectus femoris has a biarticular role being also a flexor of the hip. The action of the quadriceps has the utmost importance for both locomotion and static positions. With muscular contraction of the quadriceps standing up from a sitting position or walking up stairs are achieved. The contraction of the quadriceps can suddenly extend the knee to get a longer step when walking. With all these different actions the quadriceps is certainly the most important muscle in human locomotion.

In patellar reflex, the quadriceps is the organ for reception of the reflex and also is the effector of that reflex. Sensory and motor nerves go through the femoral nerve while the reflex center situated in the lumbar region of the vertebral column (L2–4) coordinates the reflex action. If the quadriceps is paralyzed, the patient cannot sustain the upright position.

3.10.3 Muscles of the Medial Region of the Thigh (Adductors)

Musculus pectineus, adductor longus, adductor brevis, and *adductor magnus* are uniarticular with exception of the *gracilis* and *tensor fasciae latae*. All medial muscles of the thigh have the origin on the pubis bone with exception of the tensor fasciae latae. Adductor muscles with their origin

somehow cover the obturator foramen of the pelvis. From these origins the fasciculi descend toward the femur where they insert dorsally. The adductors form a triangle shape with the base upward and the tip downward. Adductors are laid down in three sections: The *superficial section* includes the *pectineus*, *adductor longus*, and *gracilis*. The *middle section* includes the *adductor brevis*. The *deep section* includes the *adductor magnus*.

The action of the adductors depends on how they are situated toward the axes of the coxofemoral articulation.

1. Because they are situated medially and under sagittal axis, their primary action is the adduction of the femur.
2. They are not laid down strictly frontal. They in fact have the variability to act with flexion and extension on the transversal axis.
3. Adductors can also act as external rotators (except adductor magnus, which acts as internal rotator) related to vertical axis.

Musculus pectineus is situated on the top between the rest of the adductors. It has a rectangular shape. *Insertion:* The origin is on the superior ramus of the pubis. It is distally inserted between the lesser trochanter and linea aspera of femur. *Action:* It is a flexor of the femur. As a secondary action, it is an adductor end external rotator of the femur. *Connections:* It has connections with femoral vessels and the profound lymphatic's ganglions. Innervations are given by the femoral nerve (L2, 3, 4).

Musculus adductor longus is situated between adductor brevis and adductor magnus which are situated internally. Adductor brevis is situated above adductor longus. *Insertion:* The origin has a long and forceful tendon which is inserted on the anterior surface on the pubis. The distal insertion is on the linea aspera on the back of the femur. *Action:* It is an adductor of the femur. It can assist in the flexion of the femur and also lateral rotation of the femur. Innervations are assured by obturator nerve (L2, 3, 4).

Musculus adductor brevis is situated under the pectineus muscle. *Insertion:* The origin is on the frontal surface of the inferior ramus of the pubis. The distal insertion is on the lower two-third of the pectineal line and the upper half of the linea aspera. *Action:* It is an adductor of the femur and assists flexing the femur at the hip joint. Innervations are given by the obturator nerve (L2–L4).

Musculus adductor magnus is the largest muscle from the medial region of the thigh. *Insertion:* The origin of the anterior fibers is on the ramus

of pubis. The posterior fibers are on the ischial tuberosity and ramus of ischium. The distal insertion of the anterior fibers is on the linea aspera of the femur. The posterior fibers are on the adductor tubercle/medial epicondyle of the femur. *Action:* It is an adductor of the femur. It can assist by flexing and medially rotating the femur. Also is an extensor and lateral rotator of the femur. Innervations are assured by the obturator nerve (L2, 3, 4) for the anterior fibers.

Musculus gracilis is the only muscle from the adductors which goes laterally over the knee joint. It is situated most medially on the thigh. *Insertion:* The origin has a wide and thin tendon which is on the inferior part of the pubis. The distal insertion terminates on the medial and lateral part of the tibia under the tibial tuberosity. *Action:* Adductor of the femur. When the knee is flexed, it can assist flexing and medially rotating the femur. Innervations are given by the obturator nerve (L2, 3, 4).

Tensor fasciae latae has a rectangular shape and is situated laterally at the unification of the gluteus maximus and lateral superior part of the thigh. From a topographic point of view, the tensor fasciae latae belongs to the thigh that is why the author considered to be described here. *Insertion:* The origin is on the anterior and outer part of the iliac crest and outer surface of the anterior superior iliac spine. For the distal insertion, it will unify with the *iliotibial tract (band)* below the greater trochanter. It continues and distally inserts the iliotibial tract to the lateral condyle of the tibia. *Action:* It is a flexor, abductor, and medial rotator of the femur. It can stabilize the knee in extension. Innervations are assured by superior gluteal nerves (L4, 5, S1).

3.10.4 Muscles of the Dorsal Region of the Thigh (Flexors)

There are three muscles covering the posterior region of the thigh. *Musculus biceps femoris, semitendinosus,* and *semimembranosus.* These muscles are antagonists of the quadriceps. They are extensors of the coxofemoral articulation and flexor of the knee. They act as biarticular muscles. By their extension action on the coxofemoral articulation they sustain the vertical position of the body.

Musculus biceps femoris is situated at the posterolateral of the thigh. It has two heads of insertion. The long head portion is attached to the pelvis and the short head is attached to the femur. *Insertion:* The origin of the long head is on the ischial tuberosity and the short head origin is on the linea aspera of the femur at two-thirds of the supracondylar line. Distal insertion is on the lateral side of the fibula.

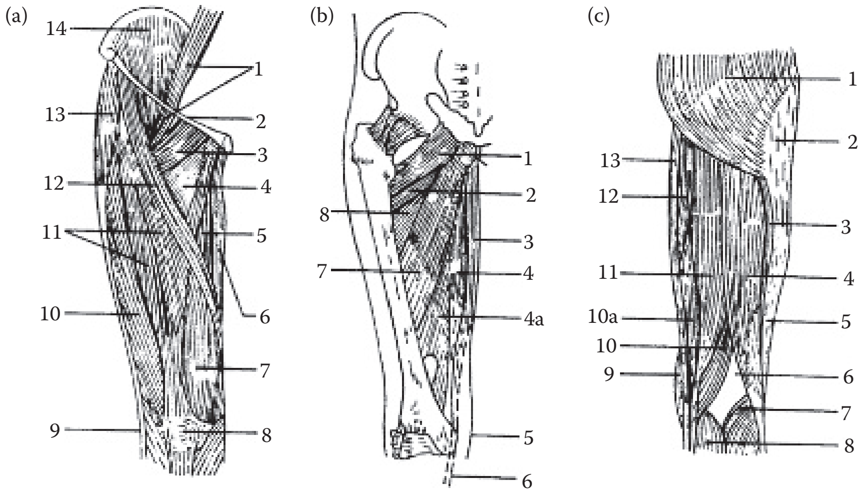


FIGURE 3.17 (a) Ventral muscles of the thigh. 1. Psoas major; 2. inguinal ligament; 3. pectineus; 4. adductor longus; 5. adductor magnus; 6. gracilis; 7. vastus medialis; 8. patella; 9. iliotibial tract; 10. vastus lateralis; 11. rectus femoris; 12. sartorius; 13. tensor fasciae latae; 14. iliacus.

(b) Medial muscles of the thigh. 1. Pectineus; 2. adductor brevis; 3. gracilis; 4. and 4a. adductor magnus; 5. skin; 6. tendon of gracilis; 7. adductor longus; 8. adductor brevis.

(c) Dorsal muscles of the thigh. 1. Gluteus maximus; 2. tensor fasciae latae; 3. biceps femoris (short head); 4. biceps femoris (long head); 5. iliotibial tract; 6. popliteal fossa; 7. plantaris; 8. gastrocnemius (medial and lateral head); 9. sartorius; 10. and 10a. semimembranosus; 11. semitendinosus; 12. adductor magnus; 13. gracilis.

Connections: Biceps femoral is covered at the superior part by gluteus maximus. At the inferior margin of the gluteus maximus, biceps femoral covers adductor magnus. The distal tendon of the biceps femoris is in immediate contact with the lateral ligament of the knee. The peroneal nerve descends from popliteal space and joins the tendon of the biceps.

Action: Long head is an extensor of the hip, and both head flex and laterally rotate the knee. Innervations are given by the long head with the sciatic nerve of the tibial portion (S1, 2, 3, and L5), and the short head with the sciatic nerve of the peroneal/fibular portion (S1, 2, and L5).

Musculus semitendinosus is situated on the posteromedial part of the thigh and extends between the ischial tuberosity and the tibia bone. *Insertion:* The origin is on the ischial tuberosity. The bulk of this muscle

is gently divided by a tendinous intersection. Distal insertion is on the anterior proximal tibial shaft. *Action:* It is an extensor of the femur and a flexor of the knee. It has more force than biceps femoris. Innervations are given by the sciatic nerve having two branches (L5 and S1, 2).

Musculus semimembranosus is situated under the semitendinosus muscle and at the medial side of the thigh. *Insertion:* The origin is on the ischial tuberosity. Distal insertion is on the posterior and medial side of the tibial condyle. *Action:* It has the same action as the previous muscle but is much more powerful. Innervation is given by the tibial nerve.

3.11 THE KNEE AND THE LEG

The muscles and articulations of the knee region are the most sophisticated in the human body. Basically the knee has just one muscle which is the popliteus muscle. Its origin is on the lateral condyle of the femur and its distal attachment is on the posterior proximal tibial shaft.

The knee joint functionality is represented by its ligaments, tendons, and bursae. It is important to mention some observations from a medical point of view: The knee articulations in contrast to other articulations, such as the hip, the scapulohumeral, and others are less protected by muscles. This fact explains the numerous injuries to the knee compared to other articulations. The knee is also engaged in both locomotion and static positions during a lifetime, causing it to deteriorate faster than other articulations.

The knee functions as a specific unit in two ways: 1. *Articular surfaces* and 2. *attachments* (ligaments, bursae, tendons, and capsulae). Both are described below.

1. *Articular surfaces: Inferior epiphysis of the femur, superior epiphysis of the tibia,* and *patella*. The fibula has no articular surface for joint connection. For better understanding of the biomechanical function of the knee joint, the author describes some details about the shape of the medial and lateral femoral condyles and how they are oriented.

   a. The articular surfaces of the femur epiphysis represented by two condyles (lateral and medial) are curbed backwards and that is why its largest part is situated behind the femur vertical axis.

   b. The lateral condyle is more apparent than the medial condyle. The medial condyle is situated lower than the lateral condyle. There are other biomechanical conditions, which will not be described here.

Another articular surface is the *dorsal part of the patella* which is connected to the ventral part of the femur. The patella has two slopes with two margins (lateral and medial). The ligamentous continuation of the quadriceps femoris tendon extends beyond the distal portion of the patella and attaches to the tuberosity of the tibia. In fact, the connection of the quadriceps femoris to the patella is called the *quadriceps femoris tendon* and the connection of the patella to the tibia is called the *patellar ligament*.

Recall that the muscles which are connected to the bones by fibrous units are called *"tendons,"* and bones which are connected to other bones by fibrous units are called *"ligaments."* This is the case regarding the connection between the patella and tibia bone.

The third articular surface is the *superior epiphysis of the tibia*. The contact and the smoothness of the movements are eased by intra-articular *menisci* (fibrous cartilages). There are two menisci (lateral and medial). The *lateral meniscus* has the shape of a circle almost closed. The *medial meniscus* has the shape of a half moon (opened toward the interior of the knee joint). Both menisci are united at the ventral part by transverse ligament of the knee. Figures 3.18a and 3.18b illustrate the articular surfaces of the knee joint and also show the menisci.

2. *Attachments: Capsula* is a fibrous sleeve. The inner layer is synovial and the outer layer is fibrous. The capsulae covers and unites the femur, patella, and tibia.

Ligaments: Patellar ligament is a very strong fibrous unit approximately 5–6 cm long and 2–3 cm wide and it lies across the front of the patella. It has a triangular shape. The origin of insertion is on the top of the patella and the distal insertion is on the inferior part of the tibial tuberosity. On the ventral part of the patella, there is a mass of adipose tissue. Below that mass are serous bursae.

3.11.1 Dorsal Ligaments

There are eight ligaments which hold the knee joint together: *Oblique popliteal ligament, arcuate popliteal ligament, fibular collateral ligament, tibial collateral ligament, anterior cruciate ligament, posterior cruciate ligament, anterior meniscofemoral ligament,* and *posterior meniscofemoral ligament.*

Oblique popliteal ligament, with its popliteus muscle, is relatively short. Its insertions have been described in the beginning of this chapter (see

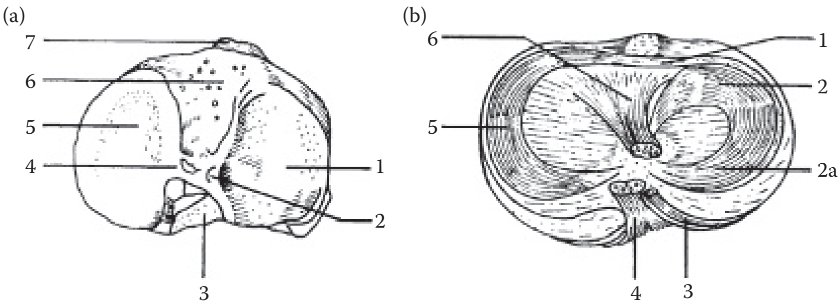


FIGURE 3.18 (a) Tibia superior articular surface (proximal epiphysis). 1. Tibial lateral surface; 2. intercondylar tubercle (lateral part); 3. posterior intercondylar surface; 4. intercondylar tubercle (medial part); 5. tibial medial surface; 6. ventral intercondylar surface; 7. tibial tuberosity.

(b) Menisci of the knee and surrounding ligaments. 1. Transverse ligament; 2. and 2a. lateral meniscus; 3. posterior meniscofemoral ligament; 4. posterior cruciate ligament; 5. medial meniscus; 6. anterior cruciate ligament.

popliteus muscle). *Arcuate popliteal ligament,* origin of insertion is on the lateral condyle of the femur and distally inserts on the lateral side of the head of the fibula. *Fibular collateral ligament,* origin of insertion is at the superior part of the lateral epicondyle of the femur. The distal insertion is on the head of the fibula on the anterolateral side. This ligament is in contact with femoral fascia.

Tibial collateral ligament, origin of insertion is on the superior part of the medial condyle of the femur and distally inserts on the medial condyle of the head of the tibia. The fibers of this ligament represent three kinds of appearance: vertical, descendant oblique, and ascendant oblique. This ligament is in direct connection with the meniscus, and the tendon of the semimembranosus muscle. *Anterior cruciate ligament* and *posterior cruciate ligament* lie within the joint capsule, but they are outside the joint cavity. Both cruciate ligaments are covered by the synovial membrane. *Anterior* and *posterior meniscofemoral ligaments* are in direct insertion with the menisci and the femur bone. These dorsal ligaments are represented by Figure 3.19a and 3.19b.

The ventral part of the knee has not been illustrated; however, the reader should know that the main part of the knee consists of the patella which is palpable easily and is covered by the quadriceps femoris connecting to the patellar ligament. The patella is also covered laterally by the medial and lateral patellar retinaculum.

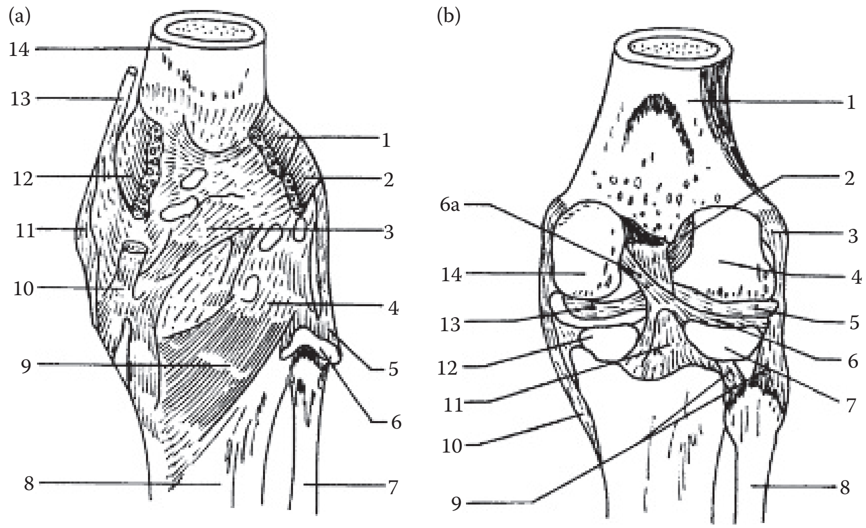


FIGURE 3.19 (a) Right knee joint, dorsal superficial layer (ligaments, tendons, muscles). 1. Plantaris muscle; 2. lateral head of the gastrocnemius muscle; 3. oblique popliteal ligament; 4. arcuate popliteal ligament; 5. fibular collateral ligament; 6. fibula joint; 7. fibula; 8. tibia; 9. popliteus muscle; 10. tendon of semimembranosus; 11. tibial collateral ligament; 12. medial head of gastrocnemius muscle; 13. tendon of adductor magnus; 14. femur.

(b) Right knee joint, dorsal deep layer (ligaments, tendons, muscles). 1. Femur; 2. anterior cruciate ligament; 3. fibular collateral ligament; 4. lateral condyle of femur; 5. lateral meniscus; 6. and 6a. posterior meniscofemoral ligament; 7. lateral condyle of tibia; 8. fibula; 9. capsular ligament; 10. tibial collateral ligament; 11. posterior cruciate ligament; 12. medial condyle of tibia; 13. medial meniscus; 14. medial condyle of femur.

The knee articulation is protected by other anatomical formations, such as the fascia of the knee, medial and lateral patellar retinaculum, synovial membrane, suprapatellar bursa, and infrapatellar adipose tissue. These anatomical formations have a role in ligament connection; they assure a better and softer protection of the knee in case of impact.

3.11.2 Biomechanics of the Knee

The femorotibial (knee) articulation can execute two major movements: *flexion* and *extension*. Additional slight movements are *internal* and *external rotations*, and very slight *medial* and *lateral abduction/adductions*.

Flexion is executed around the transversal axis which goes through the femoral condyles. These condyles represent many curved radii. Flexion

will occur with three different movements: 1. rotation of the femur epiphysis on the tibia, 2. rolling/gliding motion of the two epiphysis on each other, and 3. expansion of the joint capsule by synovial fluid motion which eases the gliding motion. At the beginning of the flexion action there is a rotation of the femoral condyles. Toward the end of the flexion, the rotation changes into a gliding action.

The movement of flexion takes place in the meniscofemoral point. The principal muscles which execute the flexion of the knee (it is customary to use the term: "flexion of the leg") are: the biceps femoral, semimembranosus, and semitendinosus. Secondary muscles are gracilis and sartorius. Flexion and extension of the knee joint works through third-grade lever system. The flexion of the leg of a normal human can reach a 130° degree angle. However, it can also reach a 170–175° angle as well.

Extension is the opposite movement to flexion. An extension takes place at the meniscotibial point. During the extension, a slight external rotation occurs. The principal muscle is the quadriceps, helped by the tensor of fasciae latae. Movements of medial/lateral rotation and abduction/adduction of the leg are more reduced in their angle of determination and will not be described here.

3.12 THE LEG

The muscles of the leg are grouped asymmetrically around the tibia and fibula. Neither the medial nor the lateral malleolus are covered by muscle. The shape of the leg is conic with the base at the top. The muscles of the leg are categorized into three groups:

1. *Ventral muscles* (extensors) including *musculus tibialis anterior, extensor hallucis longus, extensor digitorum longus,* and *fibularis (peroneus) tertius.*

2. *Lateral muscles* include two muscles: *Musculus fibularis (peroneus) longus* and *fibularis (peroneus) brevis.*

3. *Dorsal muscles* (flexors), which are subgrouped in *superficial layers,* include *musculus gastrocnemius, soleus,* and *plantaris.* The second subgroup is the *deep layer* which includes *musculus popliteus, flexor digitorum longus, tibialis posterior,* and *flexor hallucis longus.*

These muscular groups are embedded in different compartments, divided by the tibia, fibula, their interosseus membrane, and also the intermuscular septum. The intermuscular septum serves as an aponeurotic

fascia at the proximal end of the muscles of the leg adding an extra surface of insertion next to the bones. At the distal end (ankle), the aponeurotic fascia also protects the tendons by surrounding them.

3.12.1 Ventral Muscles (Extensors)

Musculus tibialis anterior is the most voluminous muscle in the ventral part of the leg. *Insertion:* The origin is on the lateral condyle and the lateral shaft of the tibia and interosseus membrane. Distal insertion is on the medial and plantar surface at the base of the first metatarsal bone and medial cuneiform. *Action:* It is the most powerful dorsiflexor of the ankle and it also inverts the foot. Innervations are assured by deep peroneal nerve L4, L5, and S1. *Connections:* Tibialis anterior is covered by the skin and the fascia. The dorsal part of the muscle is covered by interosseus membrane.

Musculus extensor hallucis longus is situated between tibialis anterior and extensor digitorum longus. It has a penniform shape. *Insertion:* The origin is on the half and middle anterior shaft of the fibula. Distal insertion is on the base of distal phalanx of the big toe. *Action:* It dorsal flexes the ankle. It is an extensor of both phalanges of the big toe. It has a slight action in the inversion of the foot. Innervation is assured by deep peroneal nerve.

Musculus extensor digitorum longus is a long muscle and is situated laterally from the previous two muscles described herein. *Insertion:* The origin is on the lateral condyle of the tibia and upper two-thirds of the anterior shaft of the fibula. The origin is very close to the interosseus membrane, however, has no connection to that. The tendon of this muscle divides into four parts and goes along the dorsal surface of the four lateral toes. It inserts distally on the middle and distal phalanges. *Action:* It is a strong dorsiflexor of the ankle and assists in the eversion of the foot. It is an extensor of the metatarsophalangeal joints. Innervation is assured by deep peroneal nerve.

Musculus fibularis (peroneus) tertius represents a small portion of the extensor digitorum longus. *Insertion:* The origin is on the lower third of the anterior part of the fibula and interosseus membrane. Distal insertion of this muscle is on the dorsal surface of the fifth metatarsal base. Its tendon for distal insertion lies under the retinaculum of all the extensor muscles. *Action:* Dorsiflexor of the ankle and everts the foot. Innervation is assured by the deep peroneal nerve. Ventral muscles are shown by Figure 3.20a.

3.12.2 Lateral Muscles

The lateral side of the leg is represented by two muscles. *Musculus fibularis (peroneus) longus* is the most superficial muscle of the leg. *Insertion:* The

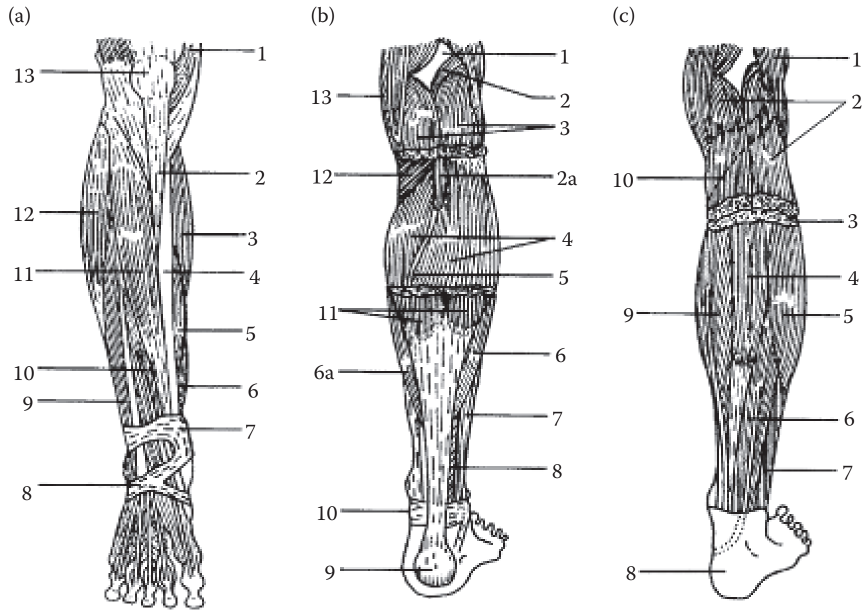


FIGURE 3.20 (a) Ventral muscles. 1. Quadriceps femoris (vastus medialis); 2. patellar ligament; 3. gastrocnemius (medial head); 4. tibia; 5. soleus; 6. flexor digitorum longus; 7. superior extensor retinaculum; 8. inferior extensor retinaculum; 9. extensor digitorum longus; 10. extensor hallucis longus; 11. tibialis anterior; 12. fibularis longus; 13. patella.

(b) Dorsal muscles (superficial layers). 1. Popliteal surface; 2. and 2a. plantaris; 3. gastrocnemius; 4. soleus; 5. plantaris ligament; 6. and 6a. soleus; 7. fibularis brevis; 8. flexor hallucis longus; 9. calcaneal tuberosity; 10. flexor retinaculum; 11. gastrocnemius; 12. popliteus; 13. sartorius.

(c) Dorsal muscles (deep layers). 1. Biceps femoris (short head); 2. gastrocnemius; 3. soleus; 4. tibialis posterior; 5. fibularis longus; 6. flexor hallucis longus; 7. fibularis brevis; 8. skin layer; 9. flexor digitorum longus; 10. interrupted lines represent the popliteus under the gastrocnemius muscle.

origin is on the lateral side of the head of the fibula. The origin is also connected to the two intermuscular septum and fascia crural. The tendon of this muscle is very long and turns twice. It descends toward and behind the lateral malleolus, then crosses the fibularis brevis, and then enters into the plantar groove and connects to the first cuneiform bone of the tarsals. The second insertion is on the base of the first metatarsal bone. *Action:* Foot eversion, assists plantar flexion. Innervation is given by the superficial fibular nerve.

Musculus fibularis (peroneus) brevis is the second muscle of the lateral side of the leg region. *Insertion:* The origin is on the lateral surface (lower two-thirds) of the fibula. It has contact with both intermuscular septums. Distal insertion is on the lateral surface of the base of the fifth metatarsal. *Action:* Everts the ankle joint and assists in plantar flexion. Innervation is given by superficial fibular nerve. Illustrations of the lateral muscles are not provided.

3.12.3 Dorsal Muscles (Flexors)

3.12.3.1 Superficial Layers

The dorsal superficial region is represented by three muscles. They are *musculus gastrocnemius, soleus,* and *plantaris.*

Musculus gastrocnemius has two heads with two origins and continues with a single common tendon. *Insertion:* The origin of the medial head is on the medial epicondyle of the femur and is longer and stronger than the lateral head. The origin of the lateral head is inserted on the lateral epicondyle of the femur. Each tendon continues with an aponeurotic fascia found superficially on the dorsal part of the muscle. On the deeper layer and lower part, there is an aponeurotic fascia for each section of this muscle. Between the two fascias, all the muscular fibers are laid down. Distal insertion for both heads is on the calcaneus bone via the Achilles tendon. *Action:* Plantar flexor of the ankle assists flexion of the knee. Innervation is given by tibial nerve (S1 and S2).

Musculus soleus is a thick muscle and is situated under the gastrocnemius. *Insertion:* Dorsal part of the head of the fibula and on the soleal line of the tibia. Distal insertion is on the dorsal surface of the calcaneus together with the tendon of gastrocnemius (Achilles tendon). *Action:* It is a plantar flexor. Contracting the entire soleus muscle helps maintain the vertical erect position of the human body. Innervation is given by the tibial nerve.

Gastrocnemius and soleus muscles are also called *triceps sural.* Soleus muscle has shorter fibers than gastrocnemius and is uniarticular. It is a muscle of force and endurance. Gastrocnemius is a muscle for speed and actions of short duration.

Musculus plantaris has the shape of a fusiform and is very thin. *Insertion:* The origin is on the lateral part of the supracondylar ridge of the femur and it descends into the popliteal surface. From the popliteal surface it descends to the medial part of the tibia. Distal insertion is on the Achilles tendon. *Action:* It is a flexor muscle. It assists in knee flexion. Innervation is assured by the tibial nerve. Dorsal muscles of the superficial layers are shown by Figure 3.20b.

3.12.3.2 Deep Layers

The deep flexor muscles are *musculus popliteus, flexor digitorum longus, tibialis posterior,* and *flexor hallucis longus.* Under the description of the knee only one muscle, the popliteus, was mentioned. The popliteus muscle was shown in Figure 3.19a and will now be described.

Musculus popliteus is a short muscle with a triangular shape. *Insertion:* The origin is on the lateral condyle of the femur. The distal insertion is on the upper part of the posterior surface of the tibia and it is superior to the soleal line. *Action:* It is a flexor of the leg on the thigh, however it is not significant. It is a medial rotator of the tibia on the femur when the leg is lifted up from the ground. Innervation is given by the tibial nerve. *Connections:* Superficial part of the popliteus is in contact with gastrocnemius, plantaris, and popliteal vessels and the tibial nerve.

Musculus flexor digitorum longus is the most medial muscle from the deep region. *Insertion:* The origin is on the posterior part of tibia under the soleal line. From here it crosses the tendon of tibialis posterior and continues down over the medial malleolus groove. It crosses over the tendon of the flexor hallucis longus (on the plantar region) and distally inserts with its four tendons to the distal phalanges of the second through fifth toes. *Action:* Flexes all the aforementioned four toes, it is also a plantar flexor and inverts the foot. Innervation is given by the tibial nerve. *Connections:* Covers the tibia, and it is covered by the soleus. On the plantar region, it is between the flexor digitorum brevis and the adductor hallucis. Flexor digitorum brevis and adductor hallucis will be described in Section 3.13.

Musculus tibialis posterior is situated deep in the leg. *Insertion:* The origin of this muscle is on both bones (tibia and fibula) on their dorsal parts immediately under their heads and it adheres on the interosseus membrane. Tibialis posterior continues with its tendon around the medial malleolus and distally inserts on the navicular bone. With its expansions, it inserts on the tarsal and the second, third, and fourth metatarsal bones. *Action:* Inverts the foot and assists in plantar flexion.

Musculus flexor hallucis longus is the most lateral muscle from the deep region. It is very strong and has an important role in human locomotion. *Insertion:* The origin is on the dorsal surface of the fibula (from two-thirds and lower). It adheres to the interosseus membrane and distally inserts on the base of the distal phalanx of the big toe. *Action:* Flexor of the big toe and assists in plantar flexion. The dorsal muscles (deep layer) are shown in Figure 3.20c.

3.12.4 The Necessary Muscles for the Movement of the Leg

The movements between the leg and the foot and the stability of the standing position are achieved by the muscles of the leg with exception of the popliteus and plantaris muscles. The majority of the leg muscles insert on the tarsal and metatarsal bones. In leg movement, muscles participate as synergists or antagonists.

The leg movements result from how the terminal tendons are laid down at the level of the ankle and the use of the two major planes (sagittal and transverse). In talocrural articulation the muscles that pass the transversal axis, such as tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus (fibularis) tertius, are dorsal flexors. Muscles behind the transversal axis, such as peroneus (fibularis) brevis, fibularis longus, gastrocnemius, soleus, flexor digitorum longus, and flexor hallucis longus are plantar flexors.

The force of gravity is very strong at the level of the leg and foot joint (ankle) which induces the leg to incline forward on the foot of support. This action of the leg causes the plantar arch to execute a pronation (eversion). The supination is named inversion.

3.13 THE ANKLE AND THE FOOT

Recall that the muscles of the hand are exclusively lying on the palmar region; the muscles of the foot are divided into *dorsal region* and the *plantar region*. At the dorsal region there are three muscles, the *extensor digitorum brevis*, *extensor hallucis brevis,* and the *musculus dorsal interossei*. The muscles of the plantar region are divided into a *medial group* (the big toe side); *lateral group* (the small toe side), which is also called in karate, "sword foot" or "edge of the foot" (*Sokuto* in Japanese); and *intermediate group,* which is associated with the tendons that separate the medial and lateral groups.

The classification using anatomical regions is accurate; however, the correct classification is made by identifying their layers, first through fourth, which are seen during dissection. The *first layer* is the most superficial and closest to the plantar fascia. It is composed of the *musculus abductor hallucis, flexor digitorum brevis,* and *abductor digiti minimi*. The *second layer* contains the *musculus lumbricalis* and *quadratus plantae*. The *third layer* contains the *musculus flexor hallucis brevis, adductor hallucis,* and *flexor digiti minimi brevis*. The *fourth layer* contains the *musculus interossei (plantar)* and the tendons of the tibialis posterior and peroneus longus.

The above-mentioned foot muscles have their origin and insertion on the foot excluding the lumbricalis. There are other foot muscles, but they have the origins on the tibia or the fibula. These muscles have been described in the previous section, and they are: Flexor hallucis longus, extensor hallucis longus, flexor digitorum longus, and extensor digitorum longus. The muscles of the foot are short (brevis) muscles and there are different names for these short muscles.

3.13.1 First Layer (Plantar)

Musculus abductor hallucis is the most medial and superficial layer of the sole of the foot. It is the most powerful muscle from the plantar region. Under this muscle lies the plantar fascia. *Insertion:* The origin is on the tuberosity of the calcaneus bone. Also an additional origin is on the plantar aponeurosis and on the flexor retinaculum. It distally inserts on the medial side of the base of the proximal phalanx of the big toe. *Action:* Its action is to assure a static position of the body. It is also the abductor and flexor of the toe. Innervation is assured by the medial plantar nerve (L4, L5, S1).

Musculus flexor digitorum brevis is equivalent to the flexor digitorum superficialis muscle of the arm. This muscle has four fasciculi with their tendons and is fixed to the middle phalanges of the second to the fifth toes. *Insertion:* The origin is on the calcaneal tuberosity and plantar aponeurosis. It distally inserts on the middle phalanges of the second to the fifth toes. *Action:* It is the flexor of the second to the fifth toes. Innervation is assured by the medial plantar nerve (L4 and L5).

Musculus abductor digiti minimi is on the lateral side of the sole of the foot. *Insertion:* The origin is the same as for flexor digitorum brevis. It distally inserts on the lateral side of the proximal phalanx of the fifth toe. *Action:* Its primary action is to serve the static position of the human and assure curvature of the plantar portion of the foot. It is the abductor of the fifth toe. Innervation is given by the lateral plantar nerve (S2, S3). The first and second layers are shown in Figure 3.21a and 3.21b. Some muscles of the third and fourth layer are noted in Figure 3.21b.

3.13.2 Second Layer (Plantar)

Musculus lumbricals are four muscles annexed to the tendon of the flexor digitorum longus. *Insertion:* The origin is on the tendons of the flexor digitorum longus. It distally inserts on the medial side of the base of the proximal phalanges of the second through the fifth toes. *Action:* It is the flexor of the metatarsophalangeal joints and the extensor of the interphalangeal

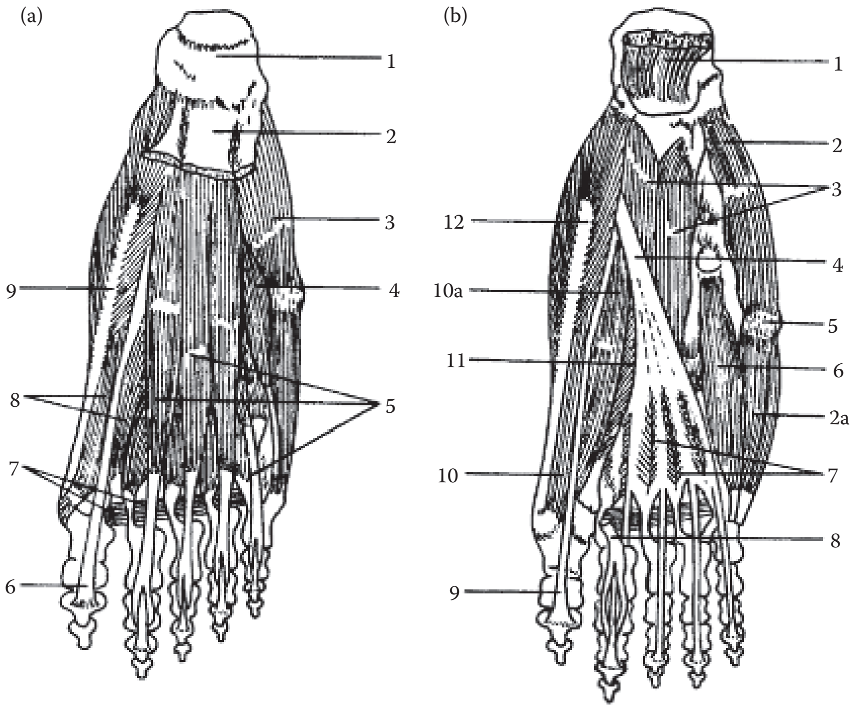


FIGURE 3.21 (a) First layer of the plantar muscles (flexors). 1. Calcaneus; 2. plantar aponeurosis (central portion); 3. abductor digiti minimi; 4. flexor digiti minimi brevis; 5. flexor digitorum brevis; 6. tendon of flexor hallucis longus; 7. adductor hallucis (transverse head); 8. flexor hallucis brevis (lateral and medial fasciculus); 9. abductor hallucis.

(b) Second layer of plantar muscles (flexors). 1. Flexor digitorum brevis (sectioned); 2. and 2a. abductor digiti minimi; 3. quadratus plantae; 4. tendon of the flexor digitorum longus; 5. tuberosity of the fifth metatarsal bone; 6. flexor digiti minimi brevis; 7. lumbricals; 8. tendon of flexor digitorum brevis; 9. tendon of the flexor hallucis longus; 10. and 10a. flexor hallucis brevis; 11. adductor hallucis (oblique head); 12. abductor hallucis.

joints of the second through the fifth toes. Innervation is assured by medial plantar nerve (L4, L5, S1).

Musculus quadratus plantae has the shape of a quadrilateral and is also annexed to the tendon of the flexor digitorum longus. *Insertion:* The origin has two fascicules. The medial head has its origin on the medial side of the calcaneus. The lateral head has origin on the lateral border of the inferior surface of the calcaneus. It distally inserts on the middle and lateral border of the tendon of the flexor digitorum longus. *Action:* It is the flexor

of the distal phalanges of the second to fifth toes. Innervation is given by the lateral plantar nerve (S1, S2).

3.13.3 Third Layer (Plantar)

Musculus flexor hallucis brevis is situated under the abductor hallucis. *Insertion:* The origin is on the medial part of the cuboid bone (plantar surface) and the lateral cuneiform bone. It is distally inserted with two fascicules. Both are on the base of the proximal phalanx of the big toe; the medial part is on the medial side and the lateral part is on the lateral side of the big toe. *Action:* It is the flexor of the big toe at the metatarsophalangeal joint. Innervation is assured by the medial plantar nerve.

Musculus adductor hallucis is situated in the middle of the plantar region. It has two fasciculi. One is oblique the other is transverse. *Insertion:* The oblique head has its origin on the base of the second, third, and fourth metatarsal and the sheath of the fibularis longus tendon. The transverse head has its origin on the metatarsophalangeal ligaments of the third, fourth, and fifth toes adjacent to the transverse metatarsal ligaments. It is distally inserted on the base of the proximal phalanx of the big toe. *Action:* It is the adductor and flexor of the big toe at the metatarsophalangeal joint. Innervation is given by the lateral plantar nerve.

Musculus flexor digiti minimi brevis. Insertion: The origin is on the plantar ligament and the base of the fifth metatarsal. It is distally inserted on the base of the proximal phalanx of the fifth toe. *Action:* It is the flexor of the little toe. Innervation is given by the lateral plantar nerve.

3.13.4 Fourth Layer (Plantar)

Musculus plantar interossei fill the space between the metatarsal bones. There are three muscles. The plantar interossei are smaller than the dorsal interossei. *Insertion:* The origin is on the medial sides of the third, fourth, and fifth metatarsal bones. Distal insertion is on the medial sides and bases of the proximal phalanges of the third, fourth, and fifth toes. *Action:* It is the flexor of the metatarsophalangeal joints and adductor of the toes. Innervation is given by the lateral plantar nerve.

3.13.5 Dorsal Region

There are only two muscles in the dorsal region *musculus dorsal interossei* and *extensor digitorum brevis* (extensor hallucis brevis).

Musculus dorsal interossei consists of four muscles. *Insertion:* They are on adjacent sides of the metatarsal bones. They are distally inserted in

this way: The first insertion is on the medial side of the proximal phalanx of the second toe. The other insertion is between all the proximal phalanges of the second to fourth toes. *Action:* They are abductors of the toes and they flex the toes. Innervation is assured by the lateral plantar nerve.

Musculus extensor digitorum brevis is connected to the four toes excluding the little toe. *Insertion:* The origin is on the anterior part of the calcaneus bone. It is distally inserted on the base of the proximal phalanx of the big toe. Also connected to the second, third, and fourth toes as adjacent to the tendons of the extensor digitorum longus. *Action:* It is the extensor of the medial four toes. Innervation is assured by the deep fibular nerve L4, L5, and S1. The dorsal region is represented by Figure 3.22. Figure 3.23 shows the bones of the foot with the majority of the muscle insertions only.

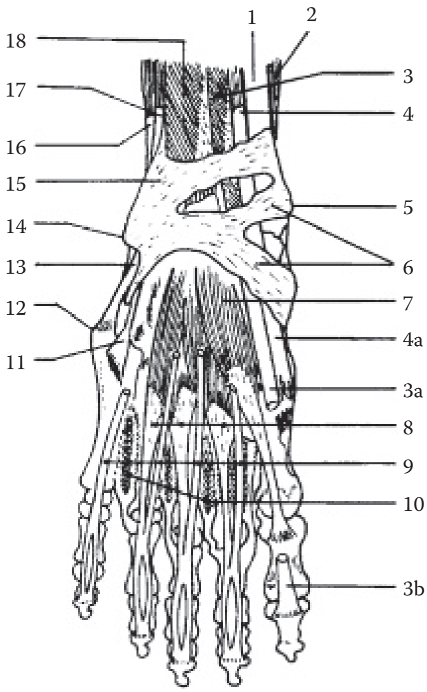


FIGURE 3.22 Dorsal muscles of the foot. 1. Tibia; 2. triceps surae; 3., 3a., and 3b. extensor hallucis longus; 4. and 4a. tibialis anterior; 5. medial malleolus; 6. inferior extensor retinaculum; 7. extensor hallucis brevis; 8. extensor digitorum brevis; 9. ligaments (extensor digitorum longus); 10. interossei; 11. fibularis tertius; 12. tuberosity of fifth metatarsal bone; 13. fibularis brevis; 14. lateral malleolus; 15. superior extensor retinaculum; 16. fibularis longus; 17. fibularis brevis; 18. extensor digitorum longus.

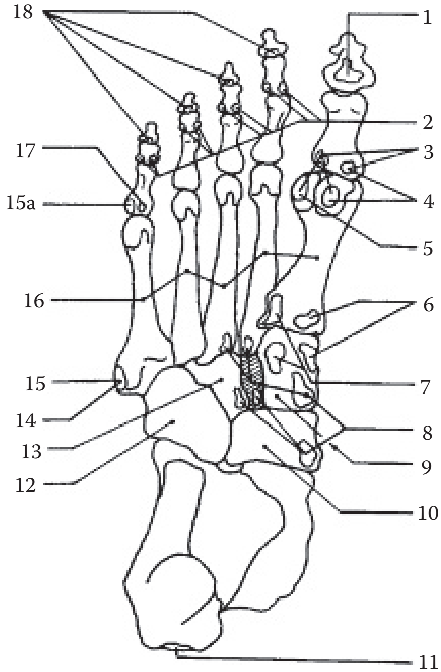


FIGURE 3.23 Muscle insertions on the plantar view of the right foot. 1. Flexor hallucis longus; 2. flexor digitorum brevis; 3. flexor hallucis brevis; 4. abductor hallucis; 5. adductor hallucis; 6. tibialis anterior; 7. fibularis longus; 8. tibialis posterior; 9. medial cuneiform bone; 10. navicular bone; 11. triceps surae; 12. cuboid bone; 13. lateral cuneiform bone; 14. fibularis brevis; 15. and 15a. abductor digiti minimi; 16. metatarsal bones; 17. flexor digiti minimi; 18. flexor digitorum longus. The shaded *area represents* the *intermediate cuneiform bone.*

3.13.6 The Plantar and the Transverse Arch of the Foot

The plantar arch or *plantar vault* controls the longitudinal or sagittal direction of the foot. The *transverse arch* represents the transverse curvature of the sole of the foot. The firmness or stability of both arches is maintained by anatomical stabilizers which can be active or passive. The muscles and some of the tendons of the leg which act on the foot are considered to be active stabilizers while some ligaments and the plantar aponeurosis are considered to be passive stabilizers.

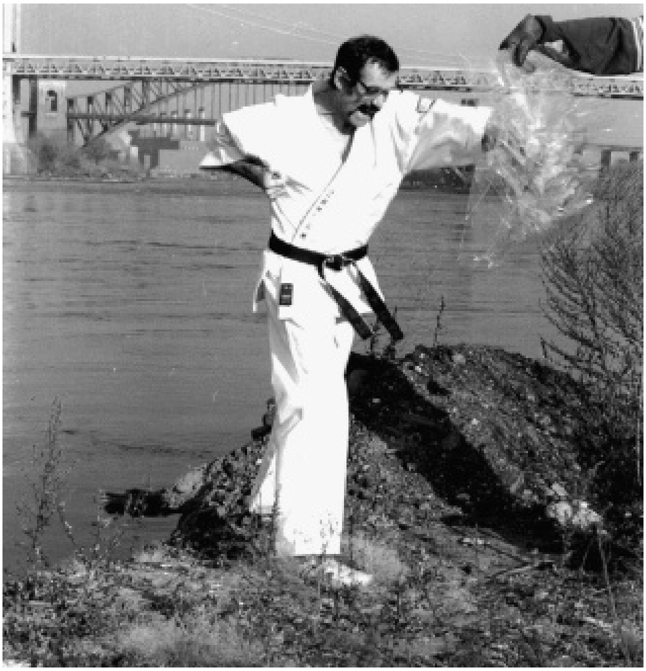
The *active stabilizers* of the longitudinal arch of the foot are abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, quadratus plantae, and abductor digiti minimi. These are the short muscles of the foot. The primary

passive stabilizers are the plantar aponeurosis, the long plantar ligament, and the plantar calcaneonavicular (spring) ligament. The flexor hallucis longus and the flexor digitorum longus are the secondary *passive stabilizers.*

3.13.7 The Movements of the Foot

In sagittal direction *dorsiflexion* is when the dorsal part of the foot approaches the leg. Another movement is the *plantarflexion* when the sole of the foot descends to the ground and the heel ascends toward the leg. In lateral direction the foot *everts* approximately 10° (the outer edge of the foot is lifted up from the ground). In medial direction the foot *inverts* approximately 20° (the inner edge of the foot is lifted up from the ground). When the inversion is strained, then the action is named *supination*.

From Figure 3.23, two tiny cartilage bones (sesamoids) are not represented. The representations of these two bones are on the area of the abductor hallucis.



Demonstration by the author: how to break five sheets of glass. It is very important to know the angle of the punching arm and where to hit the glass (refer to Chapter 11 for more detail).

3.13.8 Summary

At the beginning of this part of the book the division of the human body movement is explained. The bone structure and composition, different types of joints and the complexity of different types of muscles and their roles in the movement of the human body has been described.

In this part of the book, the focus has been on the human anatomy, particularly the joints and muscles of the body part. Part I also describes the muscle insertions, their primary mechanical actions, and the innervations of the muscles.

Some of the chapters described the biomechanics of the specific muscular region, for example, biomechanics of the knee and other body parts.

II

The Biomechanical and Physiological Foundations of Human Motion

OUTLINE TO PART II

It is assumed that a majority of fitness experts and martial arts instructors have some basic knowledge about biomechanics and its terminology, such as lever systems, center of gravity, base of support, static and dynamic activity, and even Newton's laws. However, in this part of the book, the reader will find basic explanations about how mechanics can be applied to the human muscular system.

In addition to covering a basic knowledge of biomechanics, this book will offer explanations about muscular and neurological control of movement. In Part II, the author explains succinctly the key elements that trigger motion in the human body, how this motion is controlled by the body, and how and when the nerve impulses act.

CHAPTER 4

The Concept of Muscular Mechanics

4.1 LEVER SYSTEMS, CENTER OF GRAVITY (CoG), CENTER OF MASS (CoM), BASE OF SUPPORT (BoS)

4.1.1 Lever Systems

All joint movements are rotational and can be measured in degrees or radians [1 radian (rad) = 57.3°]. Understanding lever systems is essential to know how force is applied to the movements of the body. Levers in human anatomy are basically comprised of bones that rotate around a fixed point called a fulcrum or axis. The fulcrum usually represents the joints of the bones by interconnection. A lever represents the perpendicular distance from the axis of rotation to the line of action of a force.

The length of the lever between the fulcrum and the weight/resistance is called the "resistance arm" (RA), which is, in the case of the human body, the gravity of the body part moved and any weight held or lifted by the aforementioned body part. The length between the fulcrum and the applied force/effort is called the "force arm" (FA), which is usually the contracting muscles during the effort.

The lever's role is to gain mechanical advantage whereby a small force applied at one end of the lever over a large distance produces a greater force over a lesser distance at the other end. The arrangement and structure of muscles can give a comparatively large amount of force and the arrangement of bony levers gives distance of movement and speed.

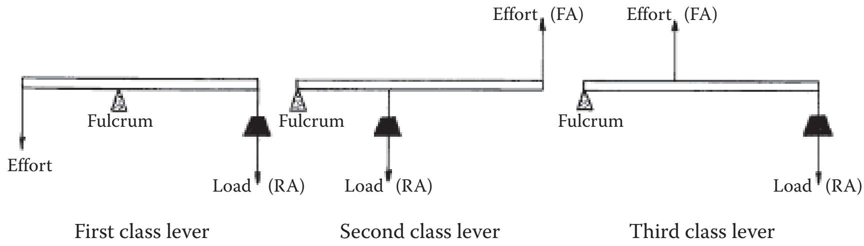


FIGURE 4.1 The three types of levers.

There are three types of levers known as *first class*, *second class*, and *third class* levers. Each works in a different way. The first class lever has its fulcrum between the resistance force arm (RA) or (R) and the effort, force arm (FA) or (F). It can be exactly in the middle of the lever or closer to RA or FA. The second class lever has its fulcrum at one end of the lever arm where the RA is closer to the fulcrum and the FA is at the other end of the fulcrum. The second class lever has a short resistance arm and this lever favors the force in action. The third class lever has its fulcrum also at one end of the lever arm where the FA is closer to the fulcrum and the RA is at the other end of the lever arm. The third class lever has a long resistance arm and this lever favors the speed in action.

Lever arms serve to increase force when the FA is longer than the RA or serve to increase speed when the FA is shorter than the RA. Figure 4.1 shows the three types of lever.

Baseball bats, golf sticks, tennis rackets, swords, and other sports instruments represent "artificial extensions of the resistance arms" of body levers, which increase the speed at the striking point but require an increased muscular force. As an example from martial arts, a karateka who has long-leg segments (long thigh and especially long leg) can very well accelerate a kick before impact. More specifically, the knee is the fulcrum (not the patella), the quadriceps muscle is the force arm (gun), and the leg, and especially the foot, is the weight or resistance arm (bullet). This is a third class lever indicated for speed. This indication is correct when we take into consideration the leg moving action, for example, the kicking leg describes a certain degree of action. Figure 4.2a explains the kicking leg action as the third class lever.

As mentioned earlier, the exact determination of the leverage of different segments of the body is rather difficult. Another example of a second

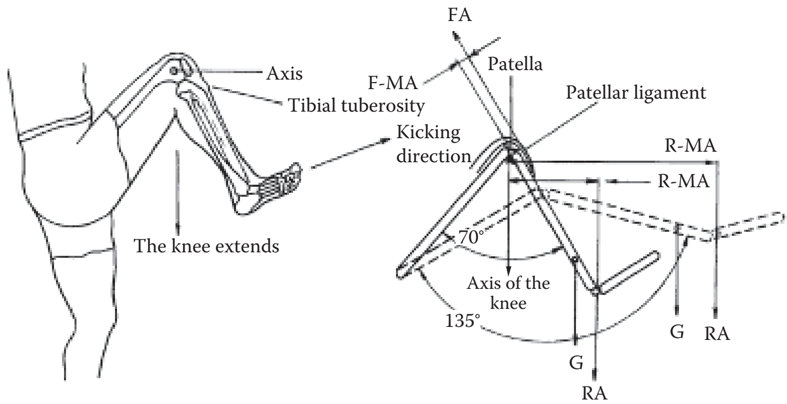


FIGURE 4.2 (a) Third class lever. During a kick the thigh, leg, and the foot will extend. The thigh and the leg describe 160–170° prior to the contact with the opponent's body. Normally the thigh and the leg should extend 180° at the time of the contact. However, the remaining 20° is used to push through the target as a penetration. During any fight, the combatants never stay stable so the attacker should always strive for the perfect 180° after the initial contact of 160°, which probable ensures the attacker a perfect kick with full force. F-MA *(force moment arm)* represents the distance between the axis of the knee and the top of the patellar ligament. The R-MA *(resistance moment arm)*, can be measured from the line of G—gravity (there are two gravity lines), which depends on the position of the lower leg at the time of kicking execution.

class lever is when the leg executes a sweeping technique (*Ashi-barai* in Japanese). In this case, the thigh and the leg muscle represent the force arm. The weight of the thigh and the CoG represent the resistance arm. The fulcrum is at the coxofemoral articulation.

This explanation is good when the kicking or sweeping foot is not snapping an opponent foot or a bag but is more of a pushing action (short action of the foot making a considerable effort to push away the obstacle). This kind of karate action can very seldom be seen. The short pushing action can be seen in judo as a sweeping action, and especially when the opponent is heavier, the attacker must make a considerable effort with his foot to take down the opponent, unless excellent timing can catch the opponent in mid-step.

While it is difficult to decide in some cases, we can say that the majority of human levers fall into first class and third class. It should be specified, that in the human body these levers are not simple long and thin bones,

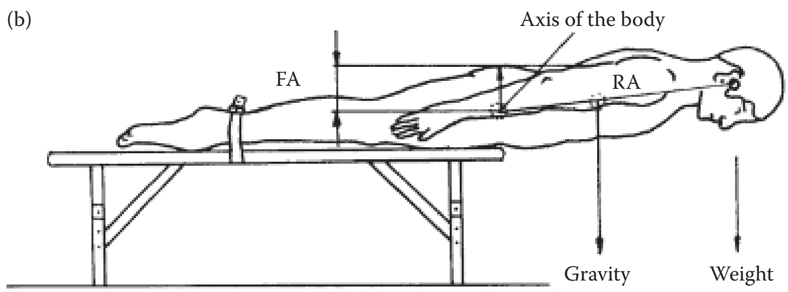


FIGURE 4.2 (Continued) (b) Third class lever.

and they can have almost any shape. Also, they are complicated systems because the lever is not represented by a single bone only, but rather by a series of bones with ligament and muscular connections.

Figure 4.2b shows another example of a third class lever system. In Figure 4.2b, the trunk of the body represents a long lever. The trunk is on prone position on a bench. The upper part of the body is in free position, the lower part of the body (only the thighs and the legs) are on the bench. The arms can be extended forward or held close to the thighs. The ankles are fixed to the bench or held by a person. The pelvis is the fulcrum at the coxofemoral articulation. The extensor muscles from the dorsal and lower part of the trunk, such as the latissimus dorsi with its toracolumbar fascia, gluteus maximus, biceps femoris long head, semitendinosus, semimembranosus, and many different ligaments, such as the sacrotuberous ligament and others, are considered to be the effort force (FA) arm. The upper part of the torso with the head is considered to be the resistance arm (RA).

The levers are strictly associated with torque, which is a force that produces a twisting motion on the axis of the rotation. More on torque and lever connections will be described in Part III of this book.

In Figure 4.2a, the leg extends and the R-MA becomes longer as the execution of the kick gains speed. The specialty literature explains that the "lever arm" and the "moment arm" are the same. The author would like to explain the tiny difference between the words *lever arm (lever)* and *moment arm*. Here is the explanation:

If we take, as an example, a rigid structure, usually a long bar fixed to a point or line where the bar "could" rotate, then the term "lever" is correct. However, when the bar is activated by two different forces such as the *effort force* and the *resistance force*, then the lever will change to the so-called *moment arm*.

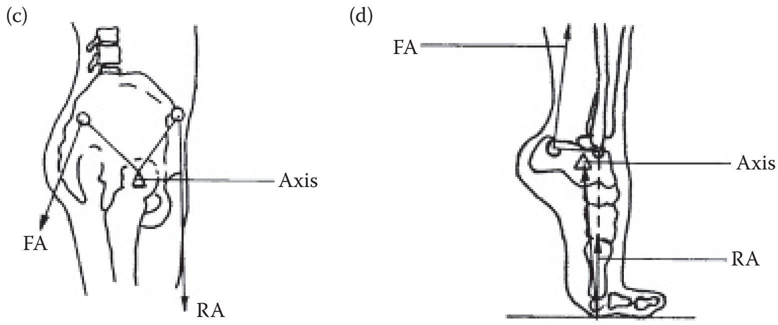


FIGURE 4.2 (Continued) (c, d) First class lever.

In this case, the moment arm has two different meanings: (a) the moment arm of a muscle force represents the shortest distance between the line of action of the force (usually a muscle) and the perpendicular distance to the axis and (b) the moment arm of the gravity or weight represents the shortest distance between the line of gravity (LoG) (which is always perpendicular to the ground) and the perpendicular distance to the axis.

Figure 4.2c and 4.2d shows two examples of first class levers. In Figure 4.2c, the coxofemoral articulation is the axis. The force arm is represented mostly by the dorsal muscles that keep the body in an erect position. The resistance arm is represented by the front part of the body, particularly the internal organs and the front of the pelvis. In Figure 4.2d, there are two possibilities for the classification of the lever system; only the first class lever is shown. The ground reaction force is treated as the resistance force, and the Achilles tendon represents the effort force (FA). If the system would show a second class lever, then the axis would be at the ball of foot and the RA represents the body weight and the FA would be represented by the Achilles tendon.

Recall that in the human body the vast majority of the levers are first and third class levers. However, here is an example of a second class lever (see Figure 4.3) in the human body (some authors would refer to it as a third class lever). This is another example of interpreting a lever in the human body. It is well known in karate and boxing that for an effective punch especially *Gyaku-zuki*—reverse punch—the athlete must use the force of the hip and shoulder (beyond) other segments. The reader can ask where and what are the levers if any (speaking about only the upper body, excluding the arms) in reverse punch execution?

Here is the answer: If we analyze the shoulder using the vertebral column as the fulcrum, the clavicle as the lever, and the head of the humerus

(with its connection to the scapula), then this kind of connection is a second class lever. Where the fulcrum is at one end of the lever, the load is in the middle of the lever and is considered to be the shoulder muscle (particularly the trapezoid), and the effort is considered to be the articulation of the humerus with the deltoid muscle, which the athlete uses for pushing or punching to execute the effort.

Usually the muscle represents the effort force. In our case (see Figure 4.3), the trapezius represents the load or weight and the deltoideus represents the FA.

However, is there a problem? The vertebral column has no connection with the clavicle. The humerus has the connection with the scapula laterally in the glenoid cavity. The clavicle has connection with the acromion by the acromioclavicular joint on the dorsal part of the scapula. Figure 4.3 shows the length of the lever arm and the advantage in the hip and shoulder leverage action.

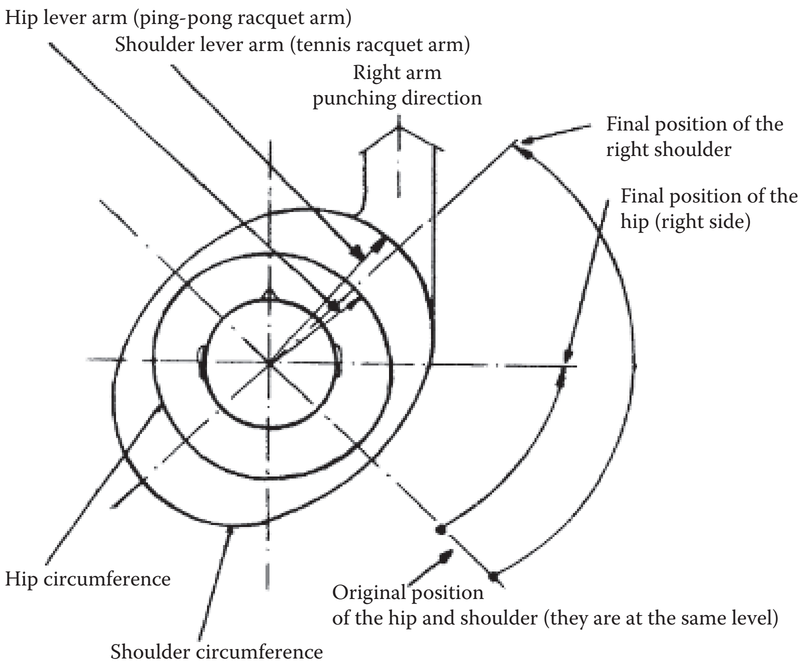


FIGURE 4.3 Second class lever. The hip turns approximately 45° while the shoulder can turn as much as 90°. The diagram is oriented from the top of the head. (From Arus E. 2005. The effectiveness of the reverse punch: A biomechanical analysis of reverse punch technique in karate and boxing. *Traditional Karate*, UK.)

The clavicle as a rigid entity represents the lever. However, the vertebral column could not represent the axis because the clavicle is attached to the sternum (sternoclavicular joint connection). Still the sternum is closer to the vertebral column so the sternoclavicular joint and vertebral column together can work as one (fulcrum) during the reverse punch.

By looking at Figure 4.3, the reader should understand that the radius of the so-called lever arm from the axis (in this case the vertical center line of the body) to the end of the lever (periphery of the hip or the periphery of the shoulder) represents a mass of muscle, which represents the FA. Practically, there is no way to know exactly the moment arm of the force, which from the end of the shoulder goes toward the neck. It is important to know that besides the shoulder FA there is also the upper portion of the arm. Those two represent the FA.

Because the shoulder lever arm is longer, this gives an edge for speed later on using the "*kinetic link principle*" over the hip lever arm. Experienced athletes transfer momentum from the hip to the shoulder and arm, for example, via tensions across the back and underarm. The shoulder has a better velocity, and the impact force of the punch will be greater due to better velocity, even if we consider that the hip produce better force. As mentioned earlier, some authors would consider this type of lever as the third class.

The reader could argue with the aforementioned statement about the hip and shoulder leverage. There is no clear-cut interpretation of the correct lever for the hip and the shoulder, but despite this, it is clear that these two body parts (hip and shoulder) must have the force and the load to deal with.

4.1.2 Center of Gravity and Center of Mass

The *center of gravity* is defined in biomechanics as the imaginary point representing the weight center of an object, where all parts exactly balance each other. In the standing position, the body's CoG is located anterior to the second sacral vertebra. The CoG is closely related to body stability and balance. The line of gravity (LoG) is an imaginary line that extends vertically through the CoG to the center of the Earth. The interrelationship of the CoG and the LoG to the BoS determines the degree of stability of the body. On each body segment, the force of gravity acts according to the body segment mass (kg), and each segment has its own CoG.

In physics, the *gravitation* is the force of attraction between particles of matter in the universe. *Gravity* is the force that attracts a body to the center

of the Earth or other celestial body. The degree of this force is measured by acceleration. Weight is an important factor in acceleration. Weight is the product of the mass of an object and the acceleration due to gravity.

Newton's law of gravitation says that any two particles of matter attract one another with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them. Newton's second law of acceleration states that any mass that changes its velocity by acceleration is directly proportional to the force causing it and inversely proportional to the object's mass.

Note: The mass of the Earth is so massive, relative to any person. The radius of the Earth is so large, relative to any human body or object dimensions, that the Earth's mass and radius become the reference to all other interpersonal gravitational forces on the surface of the Earth.

The CoM is practically the same as CoG. It is a theoretical point at which all of the body's mass is considered to be concentrated. More explicitly, the CoM is related to potential energy, more importantly to kinetic energy, when the body is in motion. Here is a mathematical equation that represents the mass, and the motion that represents specifically the velocity: the linear kinetic energy $= 1/2\ m \cdot v^2$ or rotational kinetic energy $= 1/2\ I \cdot \omega^2$, where I is the moment of inertia and ω is the angular velocity. More descriptions about the moment of inertia and the angular velocity will be provided in Part III.

Note: A Hungarian-born scientist Denes König created a theorem that says that the total kinetic energy of a system of material particles equals the sum of the kinetic energy of the CoM (assuming that the entire mass is concentrated at the CoM) and the kinetic energy of the particles in their motion relative to the CoM.

4.1.3 Base of Support

The BoS represents the area of body part(s) in contact with a resistive surface that provides a reaction force to the applied force of the body. In other words, the BoS of the body is the area occupied under the body (e.g., in standing position) and describes one continuous line united with the outer edge of the body's contact with the ground. The BoS is extremely important in any sport and especially in martial arts.

A karateka whose BoS is very wide is said to be on the defensive position. Having a larger BoS, the karateka has good balance for defending himself.

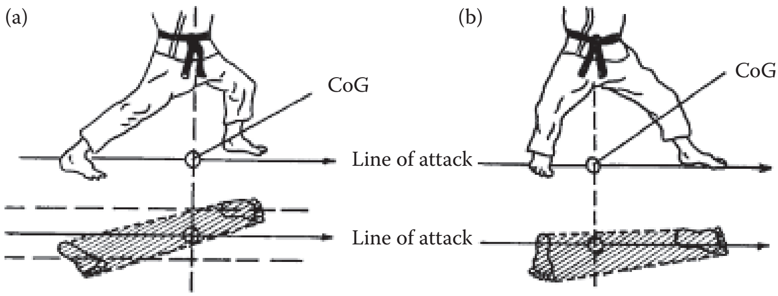


FIGURE 4.4 (a) Front stance. Gridlines represent BoS. (b) Back stance.

When a karateka's BoS is narrower, then he is on the offensive position; he can easily change his position and he can also use *Tai-sabaki*—body shifting—easily. Figure 4.4a and 4.4b shows two different BoS and also their CoG.

Figure 4.4a is a position known as *Zenkutsu-dachi* in Japanese (front stance). It is used for attack. It has a longer BoS but is narrower than the position in Figure 4.4b, which is known as *Kokutsu-dachi* in Japanese (back stance). It is used for defense. This back stance position has almost the same BoS area but because the karateka stands deeper, it is a good, solid position and has a better establishment of the CoM.

4.2 KINEMATIC CHAIN

When two or more rigid bodies are connected by joints, they are a *kinematic chain*. When we speak about bones and joints in the human body, we speak about a *multilink system function*. Kinematic chains are either *simple* (serial) or *complex* (branched). In a simple kinematic chain, there are two rigid bodies connected. In a complex system, there are more rigid bodies connected. Kinematic chains are further classified as *open* or *closed*. When the distal segment is free to move, then we speak about an *open* system, for example, the leg and the foot connected by the sophisticated joint system of the ankle. In a *closed* system of kinematic chains, constraints are imposed on both ends of the chain.

In modern biomechanics, the term *kinetic chains* is not used. In the author's opinion, there is a *kinetic chain* when we refer to the transmission of muscular force from one body segment to another. For example, in karate, when a reverse punch is executed, the force starts from the hip and continues through the lateral muscular segments of the trunk. It is then followed by the shoulder muscle force, then to the arm, the forearm, and finally to the fist.

Mobility and range of motion (RoM) are strictly related to kinematic chains. Mobility refers to articulations/ligaments (ease of motion). RoM is described as the angular displacement through which two adjacent segments move. RoM is given either in degrees or in radians. The maximal or end of RoM refers to the position where a segment cannot be moved without harming the joint itself. It should be clarified that mobility, flexibility, and elasticity have different meanings. Mobility refers to ligaments, flexibility refers to bones, and elasticity refers to the property of the muscles.

4.3 STATIC ACTIVITY

If we want to be correct about the terminology of *static activity*, then we find there is almost no muscular activity or, better said, there is a passive muscular activity, a so-called muscular tonus. Muscular tonus is a state of partial contraction that is characteristic of normal muscle; it is maintained at least in part by a continuous bombardment of motor impulses originating reflexively, and serves to sustain body posture. Static activity is strictly associated with body balance or equilibrium.

In biomechanics, static activity creates conditions in which active forces ensure different body positions and/or their segments during physical activity. There are different forces during static activity that contribute reciprocally to maintain the body's balance. These forces are either external, such as gravity and resistive force (balance), or internal through muscular force.

Body balance can be *stable* when CoG is under the BoS, for example, in gymnastics hanging on a horizontal bar (holding with hands or even with the support of the feet). The body is *unstable* or in *dynamic* balance when CoG is above the BoS, for example, standing (on two feet or one foot), sitting, head standing, or in wrestler's bridge. Maintaining a balanced position in martial arts for a long period of time is of prime importance during fighting. For instance, during a *Jiu-Kumite*—free fighting—in karate one of the opponents has been hit and he is about to fall; he is now vulnerable to receiving more hits because he is concentrating on maintaining his balance and not on defending himself.

4.4 DYNAMIC ACTIVITY AND NEWTON'S LAW

The branch of mechanics dealing with bodies that are unbalanced and in motion while under the action of force is called *dynamics*. Bodies that are studied dynamically are in accelerated motion because any amount of force acting on a body causes acceleration to that body. Dynamic activities are further subdivided into *kinematics*, which includes velocity, acceleration,

and displacement of the body or body segments without regard to the forces acting on the body, and *kinetics*, which analyzes forces that cause motion.

In dynamic activity, there are three types of motion: rectilinear, rotary, and curvilinear. Rectilinear motion *(translation)* happens when a body moves and its parts travel exactly the same distance in the same direction and in the same time. An example is a skater that moves in a straight line without waving any part of the body. Rotary motion *(angular motion)* takes place when one point of the object is fixed (to an axis of rotation) and all other points of the object rotate about the axis. The third type of motion is the *curvilinear motion*, which is a combination of linear and rotary motion. As an example from karate, a punch can start as a linear and then change to a rotary motion.

4.4.1 Important Governing Factors

In establishing body projection in space or analyzing motions, the knowledge about the CoG is very important. Recall that CoG is a theoretical point on which the total effect of gravity acts or appears to act. CoG is also a point about which the sum of torques of the body segments equals zero. The LoG is a vertical line through the CoG. If the LoG passes outside of the BoS, balance and stability are lost and the supporting limbs must move to avoid a fall. This situation is ongoing as we walk, run, and change direction.

In *Principia Mathematica Philosophiae Naturalis*, which is perhaps the most powerful and original piece of scientific analysis ever published, Sir Isaac Newton (1642–1727) laid the foundation of modern dynamics, which has still remained valid in our times. Newton's *laws of motion* express the relationships between forces, their interaction, and their effects.

Newton's first law, the *law of inertia*, states that a body at rest will remain at rest, and a body in motion tends to remain in motion in a straight line with constant velocity (no change in speed or direction) unless an external force is exerted upon it. This law originally was proposed by Galileo Galilei in 1638. It is very difficult to find any example in martial arts concerning Newton's first law. This is because a body will remain at rest only when the body is unable to move, for example, knocked out in boxing. Also, a body can remain in motion; however, the velocity and direction are being constantly changed by the opponent or by the martial artist himself.

Newton's second law, the *law of acceleration*, concerns *acceleration and momentum*. The law states that the sum of forces acting on a body in a given direction is equal to the acceleration of the body in that direction multiplied by the mass of the body. Momentum is a quantity of motion that may be

increased or decreased by increasing or decreasing either the mass or the velocity. Because acceleration is defined as the rate of change of velocity (speed, direction of motion, or both), this law also states that the sum of forces acting on a body in a given direction is proportional to the rate of change of its state of motion if the mass remains constant. Here is the equation for the second law: $\Sigma F = m \cdot a$, where F is force, m is mass, and a is acceleration (Δv is change in velocity and Δt is change in time). Note that if the sum of forces (ΣF) acting on a body is zero ($\Sigma F = 0$), such as 5 kg pulling to both left and right, the acceleration and change in velocity will be zero ($a = \Delta v = 0$). Thus, the first law of Newton is really a special case of the second law. The Greek delta Δ represents change, and the Greek sigma Σ represents total sum.

Judo provides an example for Newton's second law of motion. In order to be able to throw an opponent, especially a heavier one, a judoka must use *Kuzushi*—breaking balance. The choice is to use more mass or accelerate the execution. If your opponent is heavier than you and he pulls you forward, then you use his pulling force and add your pushing force to easily overcome and throw him on his back. If your opponent's pulling force, let us say, is 700 N and your pushing force is 800 N, the total force is 1500 N.

Newton's third law, the *law of action–reaction*, states that the force one body exerts on a second is equal in magnitude and opposite in direction to the force the second body exerts on the first. In other words, Newton's third law states that for every action, there is an equal and opposite reaction. When an athlete is jumping over an obstacle, the pushing force that athlete exerts against the Earth causes an equal and opposite reaction force from the ground.

As an example from karate, when a karateka punches an opponent, particularly into the abdominal area, with a great and penetrating force, the opposite force will be equally as great in the opposite direction (back to the attacker's punching arm). However, in this case, the kinetic energy will be absorbed into energy of destructive force and part of this force could turn into heat energy. Most importantly, the defender's body will react by absorbing the energy of the attack damaging itself.

The reader could ask that if the attacker's force absorbed/dissipates then the reaction is not the same as the action according to Newton's third law. We must know that there are changes when mechanical laws are applied to humans. In our case of hitting a soft surface, for example, abdomen, the reaction is not equal with the action (punching). The harder the surface of the target, the stronger the reaction force. Other biomechanical laws about weight, mass, speed, force, torque, moment of inertia, and impulse will be described in Part III.

CHAPTER 5

Movement Control (Muscular Physiology)

5.1 MUSCULAR CONTROL

In this chapter, skeletal muscle contraction related to a stimulus-neglecting muscle metabolism is described. Muscle is an excitable tissue, meaning that it can be stimulated chemically, electrically, or mechanically to produce a contraction. Calcium plays an important role as a cofactor to ATP, which is instrumental in the release of energy for muscular contraction.

5.1.1 Mechanics of Contraction (Sliding Filament Theory)

In Section 2.3, the basic structure of a muscle fiber and its composition are described (see Figure 2.5). Muscle contraction occurs by a sliding filament mechanism whereby the *sarcomeres* as the structural units of the myofibrils shorten (the Z-lines come together, close to each other) by the action of the *actin filaments* sliding over the *myosin filaments*. A myosin filament head is large and looks like a golf ball. The force behind a muscle contraction is the ratchet movement of the myosin heads toward the center of their sarcomere. In fact, the ratchet movement is the muscle contraction itself (Figure 5.1).

Two other proteins are part of the actin filaments, *tropomyosin* and *troponin*. During muscle contraction, Ca^{2+} and high-energy chemical compounds, such as ATP, ADP, and inorganic phosphate (P_i), have the leading role. ADP is produced when ATP is hydrolyzed (broken down)

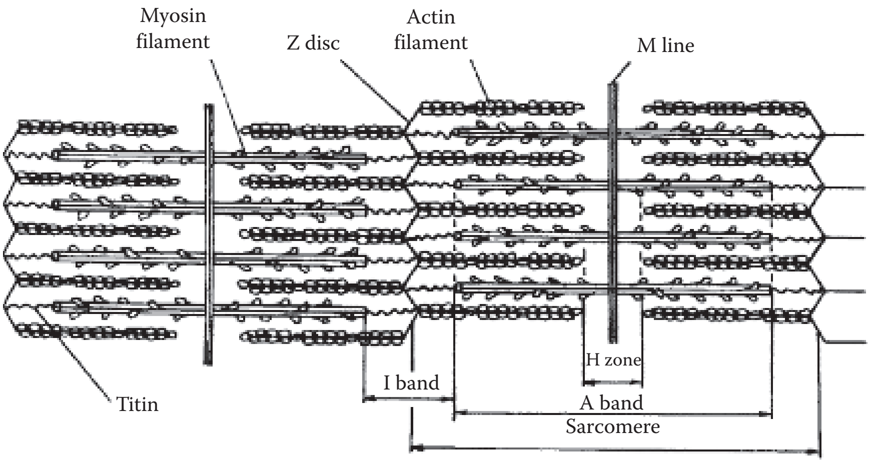


FIGURE 5.1 Structure of a myofibril and its function (sliding filament theory). See also Section 2.3.

and used as a substrate in reactions producing ATP. The transfer of the ATP, ADP, and P_i happens in the mitochondria. ATP binds to a myosin head and forms ADP and P_i. When ADP and P_i are released, the actin filament sliding motion occurs over the myosin. Below are the phases of muscle contraction:

1. ATP binds to a myosin head and forms ADP and P_i. The ADP and P_i remain attached to the myosin head.

   Ca^{2+} discloses the binding sites on the actin filaments. Ca^{2+} binds to the troponin molecule causing tropomyosin to disclose its position on the actin filament for the attachment of the myosin head.

2. Cross bridges between myosin heads and actin filaments form.

3. ADP and P_i are released and the sliding movement of actin results. The attachment of cross bridges between myosin and actin causes the release of ADP and P_i. The myosin head generates a sliding movement of the actin filaments toward the center of the sarcomere. *Z* discs are pulled together, contracting the muscle fiber to produce a *power stroke*.

4. The new ATP arrives at the myosin head, the cross bridge between the actin and myosin breaks, returning the myosin head to its former unattached position. Then the process starts all over again.

5.1.2 Action Potential

The quick change from the resting membrane potential (RMP) in electrical activity across a muscle cell or nerve cell membrane that generates an electrical current is called *action potential*. Any muscle or nerve cell has a potential electrical charge or *resting potential*, which is approximately –70 millivolts (mV). This state of a neuron is called the *polarized state*. Section 5.2 will describe in more detail the different states of *polarity*.

The action potential travels along the neuron until the end of the neuron. A gap called a *synaptic cleft* or *synapse* separates the neuron from a muscle cell or another neuron. If a neuron stimulates the muscle, then the neuron is called the *motor neuron* or *motoneuron* and its synapse is called a *neuromuscular junction*.

5.1.3 Excitation of Muscle Contraction

Muscle contraction is stimulated through the following steps:

1. The action potential generates the release of acetylcholine (ACh) from the excited neuron. The ACh is a neurotransmitter, which diffuses across the synaptic cleft.

   The action potential is generated throughout the T tubules, which are arranged in a transverse direction throughout the muscle and also travel along the sarcolemma.

2. As a result of the action potential, *sarcoplasmic reticulum* releases Ca^{2+}.

3. Myosin cross bridges form. The calcium released binds to troponin molecules on the actin helix, directing tropomyosin molecules to expose binding sites for myosin cross bridge formation (see Figure 5.2). When ATP is available, muscle contraction begins.

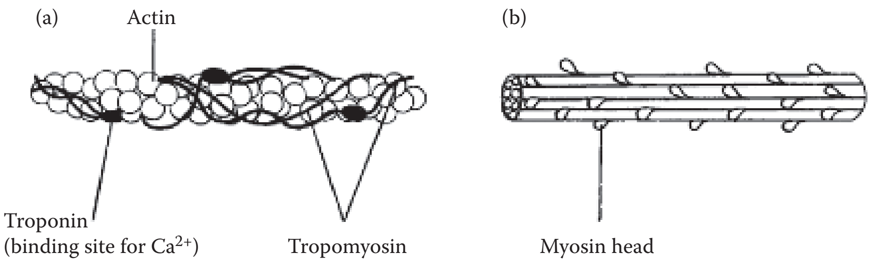


FIGURE 5.2 (a) The structure of actin (thin myofibril). (b) Myosin (thick myofibril) filaments. Some actin proteins have the binding sites for myosin (head) proteins.

5.1.4 Contributory Factors in Muscle Contraction

1. *Frequency of excitation*. Excitation can be singular or applied repeatedly to a muscle fiber; in this case, the calcium may accumulate, especially during long and repeated excitations. The muscle will have a stronger contraction. Depending upon the frequency of excitations, there are different kinds of effects.
   - *Staircase effect* or *treppe* is produced if each successive excitation occurs after the relaxation period of the previous excitation. Each successive muscle contraction must be greater than the previous one. Some other factors can contribute to the treppe effect, such as changes in pH or temperature increase and others. Generally, this stage is the warm-up period of the athlete.
   - *Wave summation* occurs when consecutive excitations are applied during the relaxation period of each preceding muscle contraction.
   - *Incomplete tetanus* occurs when the frequency of the excitations increases. In this case, successive contractions appear to be a large muscular contraction.
   - *Complete tetanus* occurs during a large muscular contraction.
2. *Strength of excitation*. More motor neurons excite more muscle fibers.
3. *Length of muscle fiber contraction.*
4. *Type of contraction*. Isotonic and isometric contraction.
5. *Type of muscle fiber.* Type I, Type IIA, and Type IIB.
6. *Muscle tone.*
7. *Muscle fatigue.*

5.2 NEUROLOGICAL CONTROL

5.2.1 Neuron

A neuron or nerve cell is the structural and functional unit of the nervous system. A neuron consists of a cell body or *soma*, an *axon*, and one or more *dendrites*. Neuron functions in the initiation and conduction of impulses.

The *soma* contains the nucleus and other cellular organelles. The *dendrites* are typically short, branched, and are thin extensions of the cell body that receives the excitation. The *axon* is a long, slender part of the cell body that sends nerve impulses. It arises from the cell body at the *axon hillock*. At this place, the density of sodium channels is very high, so this is the place where action potentials are generated.

5.2.2 Classification of Neurons by Function

1. *Sensory neurons* (afferent neurons) transmit sensory impulses usually from the skin or other sensory organs toward the CNS, which is the brain and/or the spinal cord.
2. *Motor neurons* (efferent neurons) transmit nerve impulses from the CNS toward *effectors* (muscles, sweat glands, exocrine glands, and other organs).
3. *Interneurons* or (association neurons) are located in the CNS and transmit impulses from sensory to motor neurons. Approximately 90% of the neurons of the body are association neurons.

Neurons are also classified by their type, and they are multipolar, bipolar, and unipolar neurons. The nerve cell is also known as *neuroglia(s)*, which are cells supporting and protecting neurons. There are also *astrocytes*, *oligodendrocytes*, or myelin sheaths that surround neurons and protect them.

5.2.3 Cell and Its Function

The cell is the basic functional unit of all living things. Cells can be a unicellular organism or a multicellular organism. The mammalian organism is composed of *eukaryotic cells*. *Prokaryotic cells* are simple and they represent microorganisms known as bacteria. The plasma membrane or cell membrane represents a boundary that separates the living cell from its nonliving surroundings. The cell membrane bounds the cell and encloses the nucleus of the cell and *cytoplasm*. The cytoplasm contains different organelles that are floating in a fluid that contains proteins, lipids, and carbohydrates. The different organelles are the Golgi apparatus, mitochondria, endoplasmic reticulum (ER), and others, which have different functions in the cell life.

The plasma membrane has a very important role in communicating with the outside world of the cell and controlling the movement of the materials into and out of the cell. The transport of H_2O, O_2, CO_2, lipid-soluble

molecules, and hydrocarbons can take place freely across the membrane. The crossing of the membrane happens in two ways:

Passive transport when the substances with higher concentration pass to lower concentration regions. Here, no energy expenditure is required. An example is the diffusion of water by *osmosis* or by simple diffusion.

Active transport is when the movement of solutes usually goes against a gradient with higher concentration. In this case, expenditure of energy is required, such as ATP. In neurological contraction, electrolytes, especially sodium, potassium, and chlorine, generate electric current through the membrane. This is the prerequisite for the action potential to go on.

5.2.4 Transmission of Nerve Impulses

An unstimulated neuron membrane is said to be in a *polarized* state. Polarity is when two parts of the neuron membrane (the inside of the neuron and the outside of the neuron) have different charges. The inside of the neuron cell is mostly negatively charged. It contains mostly potassium ions (K^+), negatively charged nucleic acids, and negatively charged large protein atoms. An excess of sodium ions (Na^+) reside outside of the cell. The polarized state or *resting potential* does not generate any electrical charge, which could lead to the action potential. The *resting potential* has an electrical charge of approximately −65 to 70 mV. The *graded potential* actually represents an electrical charge in resting potential.

5.2.5 Generation of Action Potential

Action potential emerges because of the dependence of the membrane permeability upon the electrolytes. The electrical charge difference is called the *membrane potential.* If a membrane of a neuron is stimulated with a small electrical voltage, then its resting potential will change a little bit to accommodate the stimulus and then will return to its resting level if no other stimulus occurs.

Resting potential to *graded potential* occurs when there is a slight electrical charge. Then, sodium or potassium channels will open. The graded potential is a local event of the neuron cell and does not travel far from its origin. This event happens more often in cell bodies and dendrites. Any pressure on the body part can act as neurotransmitter.

When positively charged sodium ions enter a cell body through its membrane, the membrane *depolarizes*, so the cell becomes more positive. If the stimulus opens potassium channels, then positive potassium ions exit across the membrane and the membrane *hyperpolarizes*, or becomes more negative.

When depolarization becomes greater by inflowing more sodium into a cell, basically from –70 to +30 mV, then the nerve has an *action potential*. At the time when sodium enters a cell, potassium leaves the cell through the potassium channels. This exchange causes a *repolarization* by restoring the original polarization of the membrane.

The membrane becomes *hyperpolarized* when potassium channels close. Then the membrane reaches approximately –70 mV. After hyperpolarization, the potassium and the sodium are on the wrong side of the cell membrane. This is a short period of time called the *refractory period*. During the refractory period, the axon will not respond to any new stimulus and the sodium and potassium pumps will reestablish the sodium and potassium location. For a better understanding of the physiology of the neurological actions during excitation, the reader should consult an exercise/sport physiology book.

5.2.6 Muscle Innervations

Recall that muscular contraction is generated not only by chemical substances but more importantly by different stimulatory agents (pain, heat, cold, electric shot, etc.) that are directed to muscular innervations centers. Innervations are generated by the complicated CNS, including the brain and the spinal cord. The brain is the primary center for regulating and coordinating body activity.

Sensory impulses are received through "afferent" nerves. These register as sensations resulting from the stimulation of sensory receptors. Motor impulses are discharged through "efferent" nerves to muscles and glands initiating activities. Through reflex centers, automatic control of body activities is maintained. The most important reflex centers are the *cardiovascular*, *respiratory*, and *vasomotor centers*, which regulate circulation and respiration.

The brain has numerous parts with different functions, but it has four major regions:

1. The *cerebrum* is composed of the right and left cerebral hemispheres with different functions. The frontal lobe is the center for the intellect and motor control. The temporal lobe is the auditory center. The

parietal lobe is the sensory information center. The occipital lobe is the visual input and its interpretation center.

2. The *diencephalon* is comprised of the thalamus and hypothalamus and is located in the middle of the brain. The *thalamus* is a sensory integration center. The *hypothalamus* has many functions but the most important is regulating the homeostasis of the body.

3. The *cerebellum* has the role of coordinating movement.

4. The *brain stem* is comprised of the midbrain, the pons, and medulla oblongata. Among many functions, the brain stem is the connection site between the brain and the spinal cord. The spinal cord is connected to the medulla oblongata and has the function of carrying sensory and motor fibers between the brain and the end organs.

In order to better understand the complicated sensory and motor innervations and its system, the following terminologies, body organs, and definitions will elucidate the muscular innervations system (see also Figure 5.3).

The CNS contains the brain and the spinal cord with nerves and end organs that control voluntary and involuntary acts.

The *peripheral nervous system* (PNS) is the portion of the nervous system outside the CNS. Included are 12 pairs of cranial nerves and 31 pairs of spinal nerves as well as all sensory nerves of the *sympathetic* and *parasympathetic* nerves. The PNS has two major branches, the sensory and the motor. The PNS sensory neurons enter the spinal cord through the dorsal root, and their cell bodies are located in the dorsal root ganglia. Motor neurons depart from the spinal cord through the ventral root.

Sensory–motor integration is the process by which the PNS transmits sensory input into the CNS, which interprets the information and then sends the appropriate motor signal to draw out the desired motor response.

Reflexes are the simplest form of motor control. These are not conscious responses. For a certain sensory stimulus, the motor response is instantaneous.

Golgi tendon organs are encapsulated sensory receptors through which a small bundle of muscle tendon fibers pass. These organs trigger a reflex that inhibits contraction if the fibers of the tendon are overstretched. These organs are located in the tendons of the muscle.

The *neuromuscular spindle* (muscle spindle) is a complex sensory nerve-ending organ in the muscle that is sensitive to stretch in which the

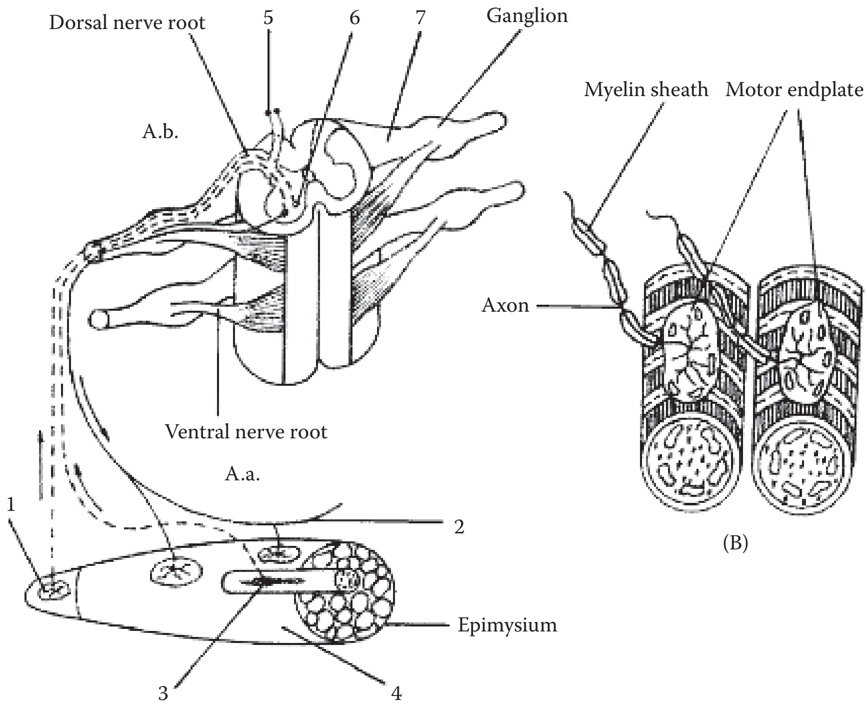


FIGURE 5.3 Sensory and motor innervation of the skeletal muscle. A.a. Section from a prime fasciculus with a single neuromuscular spindle; 1. sensory fiber at neurotendinous end (Golgi tendon organ); 2. alpha motoneuron with two motor endplate; 3. sensory fiber with neuromuscular spindle; 4. fasciculus; A.b. spinal section through the spinal marrow; 5. nerve fibers from posterior root; 6. collateral neuron synapses; 7. dorsal spinal nerve. (B) Two fasciculus sectioned with motor endplate.

afferent nerve fibers terminate. This specialized fiber is involved in the stretch (myotatic) reflexes. The contact point of this sensory nerve ending is enclosed in connective tissue sheaths also called "stretch receptors."

The *motor endplate* is a flat expansion ending in a motor nerve fiber where it connects with a muscle fiber. Alpha (α) motorneuron or motoneuron is a neuron that innervates power-producing, extrafusal muscle fibers. Gamma (γ) motoneurons are small neurons innervating intrafusal fibers and changing the sensitivity of spindle endings to muscle length (static γ-motoneurons) and to velocity (dynamic γ-motoneurons).

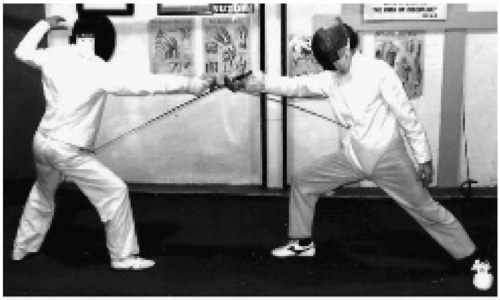
Ganglion is a mass of nervous tissue located at the dorsal spinal nerves outside of the spinal cord and composed principally of nerve cell bodies.

5.3 SUMMARY

In this part of the book, the reader was acquainted with some basic information about biomechanics and human physiology. Part II describes the lever system, base of support, center of gravity, center of mass, static and dynamic activity of the muscular chain (kinematic chain), and Newton's laws of motion and its interpretation.

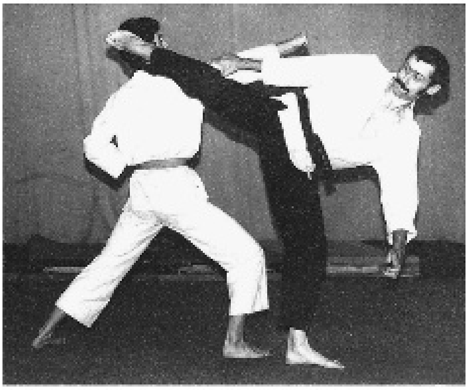
This part of the book describes the trigger factors that initiate a muscular movement, for example, about the muscular and neurological contraction, plus the contributory factors. These factors contribute to the correct movements, such as the mechanics of contraction and its neurological control that assure the movements to go on.

Aikido

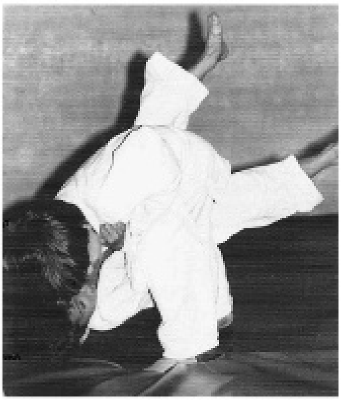


Fencing

Wrestling



Karate



Judo (children)

Boxing

III

The Fundamentals of Biomechanics

OUTLINE TO PART III

Part III describes many important concepts in the science of mechanics related to human bodies. Chapters 6 and 7 describe kinematics. Kinematics is a branch of mechanics that studies motion concerning the velocity of movement and its acceleration of different body segments. Kinematics does not take into consideration the mass and force related to the velocity and acceleration of the body. These are described as linear or rotary (angular) motions.

Chapters 8 and 9 describe kinetics. Kinetics is another branch of mechanics that studies the different forces acting on a mechanical system. These forces can act on a body in a straight line (linear kinetics) or in a rotary motion (angular kinetics).

Part III prepares the reader to better understand the general mechanical concepts related to exercise movements, which will ultimately help the reader to understand how the martial arts techniques are guided by biomechanical laws. Some core mechanics have been described in this part of the book. Part III explains the biomechanical similarities and differences between different sports and martial arts, for example, the kicking technique of the footballer and the karateka kicking technique.

CHAPTER 6

Kinematics in Linear Motion

In chapter 4, the static and dynamic activities have been succinctly described. In any sport, static activity is reduced almost to "0" percent because the athletes are always in motion. However, there are some sports activities/techniques in which static activity/balance prevails. Two examples are gymnastics (handstand position) where the gymnast has an unstable equilibrium or when the karateka stands in a one-leg stance (*Sagi-ashi-dachi* in Japanese).

Because martial arts are extremely dynamic, the author focuses almost exclusively on dynamic activities. Recall that kinematics deals with recording speed or velocity, time, displacement, and acceleration, but does not take into consideration the cause of acceleration, which is the force. In order to record or estimate the speed of an object, the recorder must know the distance.

6.1 DISTANCE AND DISPLACEMENT

Distance and displacement are measured in meters or kilometers. Distance and displacement are quantities; however, they are different in respect to their measurements. Distance represents the length, for example, from point A to point B. The distance is measured in a straight, curvilinear, or circular line and always follows the path of the distance covered.

The length of displacement is measured from point A to point B using a straight line. If an athlete covers a distance from A to B and B point coincides

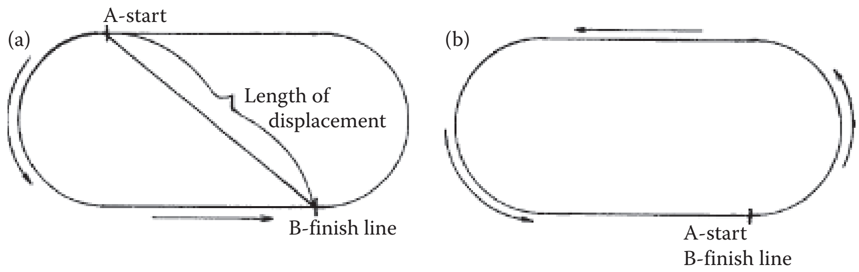


FIGURE 6.1 (a) 200 m dash = 200 m length of distance. (b) 400 m dash = 400 m distance = 0 m displacement.

with point A at the return, then the displacement is equal to "0" meters. Figure 6.1 demonstrates the difference between distance and displacement.

In martial arts, distances and displacements have less importance. When we speak of fencing, the distance covered by one or both fencers is exactly 14 m; however, here the distance covered is not important, but the time of the execution of the attacking arm, which obviously covers a very short distance, is important. In track and field, the different distances covered by the athletes under different times are recorded and are important.

6.2 SPEED AND VELOCITY

Speed and velocity are frequently used in sports terminology. The speed is related to distance covered in a given time, and velocity includes the direction of this movement. In martial arts, we speak about speed. Speed and velocity are measured in units of length per time, such as meters/second. To find out, for example, in karate, the speed of a punching fist, which starts from the hip and ends at the target, the coach should register the distance of the punching fist and divide it by the time.

For example, the result could be 0.64 m/0.12 s = 5.3 m/s speed. The 0.64 m represents the total arm length. However, manually registering such a time with the use of a time watch that has seconds and milliseconds is not very accurate. The displacement and velocity of the punching fist as it punches and withdraws to the side of the body is the following: displacement is "0" and the velocity is also "0." The average speed and the average velocity is the same when the motion is in a straight line and in one direction. Here are the mathematical formulae for speed and velocity:

$$\text{Speed} = l/t, \quad \text{where } l = \text{length of distance and } t = \text{time or m/s.}$$

The velocity is expressed by the following formula:

$v = d/t$, where v = velocity, s, r, or d = displacement, and t = time or m/s.

But all these measurements represent in fact the *average speed* and *average displacement*. If we speak about an athlete who runs the distance of 1500 m, his speed varies during the time of running. At the very beginning, his speed is higher than during the remainder of the distance, which varies again depending on the tactical solutions of the athlete or depending on his endurance. At the end, his speed will increase again as he gets closer to the finish line.

In martial arts, the speed has the utmost importance in any kind of technical execution; however, the factor of speed is negligible if the athlete has less force to sustain the speed and ultimately the acceleration. In martial arts, the result of the speed and the force are the key factors for achieving victory.

6.3 ACCELERATION

The acceleration is the time rate of change of the velocity, which means that acceleration tells us *how fast the velocity is changing.* An object can have a large velocity and zero acceleration and vice versa. Whenever a body is acted upon by an unbalanced force, it will undergo acceleration. If a body is moving in a constant straight direction, the force which is acting upon it will produce shortly a change in speed. The acting force may produce a change of speed and also a change of direction. In general, in order to produce acceleration, a force must be applied to the body.

According to Newton's second law of motion ($F = m \cdot a$), the magnitude of the force (F) must be directly proportional to both the mass (m) of the body and its acceleration (a). Acceleration is measured by meters per second squared $a = \text{m/s}^2$. An explanation is important concerning why the acceleration is measured as m/s^2. Taking the following mathematical expressions for average acceleration, which states: $\bar{a} = \Delta v/\Delta t$ or $\bar{a}$ = (final m/s − initial m/s)/s, which becomes $\bar{a}$ = (m/s)/s. Acceleration can be positive or negative. An increase is considered positive, and a decrease in speed is considered negative. The negative acceleration or slowing down also called *deceleration*. It is important to describe here that when an athlete (or an object) *speeds up*, he experiences positive acceleration; on the contrary, when the athlete *slows down*, he experiences negative acceleration. The mathematical equation is expressed as $\bar{a} = v - u/t$

where the average acceleration is $\bar{a}$, the final velocity is v, and the initial velocity is u. The *final velocity* can also be marked v_f and the *initial velocity* as v_i. A better explanation about acceleration is that

$$\bar{a} = \frac{\text{Change in velocity}}{\text{Time for the velocity to change}}$$

or

$$\bar{a} = \frac{\Delta \text{ velocity}}{\Delta \text{ time}} \quad \text{or} \quad v_f = v_i + at,$$

where $\bar{a}$ represents average acceleration. Acceleration also can be manifested due to the gravity of the Earth and its weight. It should be stated that mass (m) and weight (w) are confused by the popular mind. Mass represents the quantity of matter that an object has. Mass depends on the density and volume of an object and is constant regardless of where it is. The SI unit of mass is the kilogram (kg). Weight (w) represents the force of attraction of the gravitational pull of the earth exerted on an object. Weight is often expressed in units of mass (kg), but this is not scientifically correct. Weight, being a force, should be measured in Newton (N), and a body of mass (m) will have a weight $m.g$, where g (represents the gravity) is the acceleration of free fall (9.81 m/s^2).

From the formula $F = m \cdot a$, derive that $a = F/m$ and $w = mg$, where m is the mass in kilograms and g is the acceleration due to the gravity of the Earth. The units of gravity (g) are m/s^2 or N/kg. Vertical jump acceleration is considered in two ways: upward velocity is positive and downward velocity is negative or deceleration.

When we know the formula of weight $(w) = m \cdot g$, then we can calculate a man's force in Newton. For instance, a man with a mass of 70 kg $\times$ gravity (9.8 m/s^2) = 686 N.

Registering a velocity of execution for a very short distance (displacement) is very difficult even using a high standard registering machine for speed or velocity such as a highly sophisticated accelerometer or a camera with a high-rate speed, which could record a minimum of 30 frames per second (fps) to a maximum of 500 fps and even more. Speed/velocity and distance/displacement are expressed all together when the measurement is done for a straight line.

Recall that speed in martial arts has the utmost importance when sustained by sufficient force. The speed/velocity of an impact or impact force

is important to find out the effectiveness of the punch or a kick. Here is an example on how to find out the velocity of an impact.

For a shoulder throw, such as *Seoi-nage* or shoulder wheel *Kata-guruma*, Judoka B who will be thrown will fall on the ground from a distance of approximately 159–160 cm height (representing the shoulder height) if opponent A who throws him is approximately 184–186 cm tall. The velocity on impact is $v = a \cdot t = (9.8\ \text{m/s}^2) \cdot (0.57\ \text{s}) = 5.58\ \text{m/s}$. The 0.57 s represents how long it took for Judoka B to hit the ground. Here, we used the acceleration of gravity and neglected the acceleration given by the force exerted by Judoka A. (The equations are true only for constant acceleration.) If we want to find out the distance from the shoulder to the ground, then the equation will be $d = 1/2\ v \cdot t = (5.58\ \text{m/s})(0.57\ \text{s})/2 = 3.18/2 = 1.59\ \text{m}$ distance. So the prediction of the height of 159 cm is correct. It is important to explain about the height of the falling distance. If opponent A is tall, 184–186 cm, the action of the shoulder throw requires a forward bending/leaning of the upper body of Judoka A. The shoulder height, particularly the top of the trapezoid muscle from the ground, is 159–160 cm. Judoka B will be thrown from the shoulder level and the leaning forward represents a technical execution for easing the throwing. Figure 6.2 shows the shoulder wheel (*Kata-guruma*) technique.

6.4 MOTION WITH CONSTANT ACCELERATION

When a body maintains the same direction and magnitude (no change) during its acceleration, this condition is called *constant* or *uniform acceleration*. During constant acceleration, the body or object deals with *velocity* (v_i and v_f), *acceleration*, *time* (taken to move from initial state to the final state), and *displacement*. Kinematics offers us variable equations that are useful for different calculations. Table 6.1 shows these equations.

It should be emphasized that the equations of numbers (1) and (5) can be used only in cases when the motion is rectilinear and one-dimensional (1-D). When we speak about acceleration of an object, basically there are two kinds of acceleration:

1. When a body falls from an unspecified distance, it has acceleration due to the Earth's gravity, which is basically constant; it varies slightly from place to place on the Earth's surface. The magnitude of the acceleration due to gravity is approximately 9.8 m/s^2. If an object is thrown vertically upward and dropped, the acceleration due to gravity is noted as −9.81 m/s^2. The minus sign indicates a slowing down in the upward direction. In the case of throwing an object vertically upward, the acceleration will change to a slower rate.

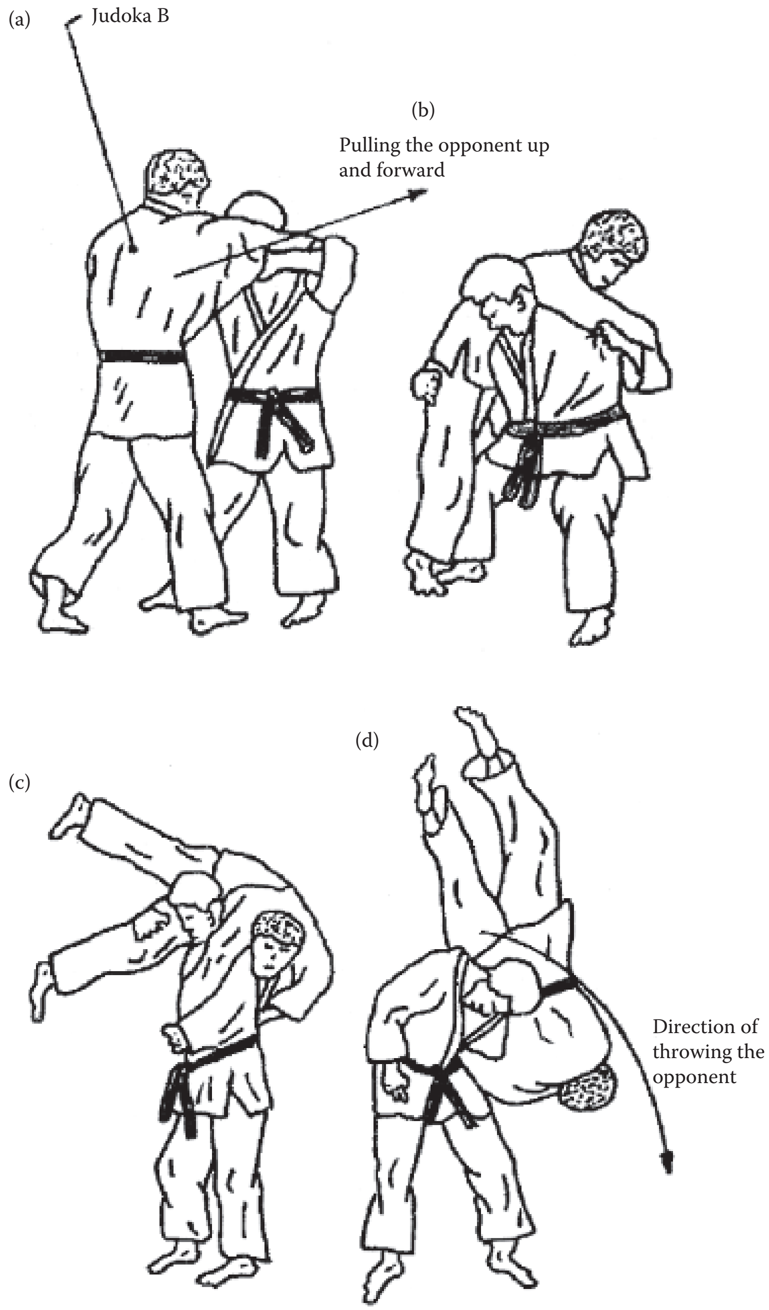


FIGURE 6.2 The shoulder wheel technique (*Kata-guruma*). (a) Off-balancing (*Kuzushi*), (b) preparation for throwing (*Tsukuri*), (c) shoulder level for throwing, and (d) actual throwing (*Kake*).

TABLE 6.1 Kinematics Equations

Equations	Functions Related to *v, a, t,* and *d*	
$a = \dfrac{v_f - v_i}{t}$ or $v_f = v_i + at$	For constant acceleration	(1)
$d = v_i \Delta t + 1/2\, a\Delta t^2$	For d as a function of t	(2)
$d = 1/2\, (v_i + v_f)\Delta t$	For d varying with v and t	(3)
$v_f = v_i + a\Delta t$	For v as function of t	(4)
$v_f^2 = v_i^2 + 2ad$	For v as function of d	(5)

2. When an athlete, for example, runner, fencer, and swimmer, changes his velocity rate, by acceleration or deceleration. For recording kinematics data (speed/velocity, displacement, and acceleration), sports specialists use different apparatuses, such as digital videos, videography, photogrammetric, accelerometers, and so on. Almost all these apparatuses require the use of different system of markers. Markers are used on the subject or for marking the distance or displacement. In martial arts, to use a marker system is not practical because the subject has very complicated motions (mostly angular). Everyone must bear one thing in mind that registering different kinematic or kinetic data is made for only comparing the athlete's result. By analyzing these results, including analyzing the biomechanical aspects/techniques, the sport specialist can help the athlete to improve the technique or the motor development quality.

To register the velocity or acceleration of a certain technique in martial arts, the subject should execute a certain technique through a distance that is longer than 3–4 m. Registering an acceleration or velocity over a long distance such as in athletics or swimming, the specialist has the possibility to see the data of velocity or acceleration by comparing different set points by reading the data on or about the "'markers" (acceleration or deceleration, etc.) and the results that can be seen by using an adequate apparatus.

The reader could ask if a karateka direct punch can be registered, looking for the velocity or acceleration. The answer is yes; however, the difference of speed between the athletes is so minuscule that mostly the impact force is registered where the difference between martial artists can be significant. Registering kinematic or kinetic variables will be discussed in Section 6.5, Scalars and Vectors.

6.5 SCALARS AND VECTORS

Physical quantities can be described as *scalar quantities* that possess only size or amount and are referred to as *magnitude* (e.g., length, mass, speed, time, volume, and temperature). The other form to describe physical quantities is *vector quantities* that possess both *magnitude* and *direction* (e.g., velocity, acceleration, displacement, momentum, force, and torque).

When a boxer executes a direct or circular punch, then the execution requires a certain amount of force (*magnitude*) and also a *direction* (of the force), which includes displacement. Scalar quantities are mostly used for the measurement of an athlete's speed or for the measurement of the mass (kg) lifted by a weight lifter. Scalar quantities are regarded as real numbers and are added by simple mathematical rules. Scalars are not associated with any direction.

Vectors are represented by a simple arrow that can show the direction and the magnitude of the velocity of an object, for example, ball and the direction of that ball. Vector components are essentially scalar values at different components of the vector. For example, if we take a karate kick execution, the magnitude of the force of the execution will be measured in Newton or (kg.f), which could be a scalar quantity, and the direction will be represented by an arrow, which is a vector quantity.

To calculate vectors and to find the location of a point (body) in space, the coordinate system is used. Two systems are well known. The *Cartesian (rectangular) coordinate system* that uses an x, y, z reference system, either two-dimensional (2-D) (two axes) or three-dimensional (3-D) (three axes), in which a point (P) is located as a distance from each of the axes.

The Cartesian 3-D system is used for cylindrical and spherical coordinates too. Usually for a 2-D system, the x, y axes are used. In 3-D system, the x axis represents the abscissa line, the y axis represents the ordinate line, and the z axis represents a perpendicular line to the x axis. All three axes have a common meeting point that is referred to as the fixed point and are numbered with "0" point.

The *polar coordinate* represents the second system. Just like the Cartesian, the polar system has a basic point of reference that is called the *pole* or the number "0." In this system, a point in space (P) is determined by the length of the vector/distance (r) from the origin (0) to the point in

space and the *angle* between the vector line (r) and the right horizontal axis, usually the abscissa of the reference system.

In the 2-D system, the point P is between the two axes of x and y and is sometimes closer to the x axis or closer to the y axis. In biomechanics, we most commonly use the 3-D coordinate systems with an extra line in space, which is usually noted with a z axis (see the explanation above). Figure 6.3 represents a 3-D system in space explaining the usage of the body planes for finding the point P.

The point P in space can be found by using the body planes, which in our case represent the following: The x–y orthogonal axes also represent the *frontal plane* of a body that divides the body into front and back parts. The x–z orthogonal axes represent the *transverse plane* of a body that divides the body into upper and lower portions. The z–y orthogonal axes represent the *sagittal plane* of a body that divides the body into right and left parts. Consulting Figure 6.3, the reader will have better understanding about body planes in the 3-D system (0–X–Y_1–Y represents the *frontal plane* of the body).

In 2-D system, there are two coordinates that are usually named x and y representing the abscissa and the ordinate vectors. The direction of the third vector z can be found by curling the fingers of the right hand around a hypothetical axis perpendicular to plane x–y so the vector x rotates along the angle a until it is aligned with vector y. The thumb then gives the direction of z. This procedure is named the *right-hand (thumb) rule*. Figure 6.4 shows the representation of the *right-hand (thumb) rule*.

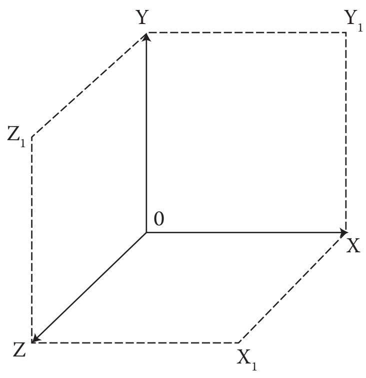


FIGURE 6.3 3-D coordinate system with body planes.

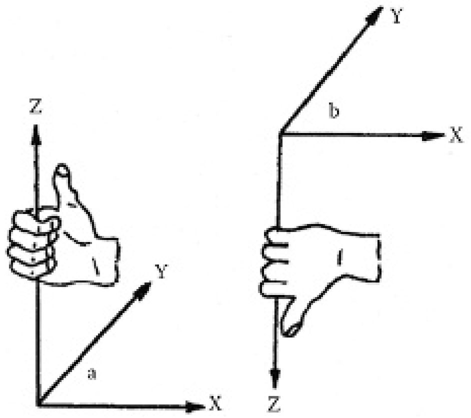


FIGURE 6.4 Right-hand coordinate system.

6.6 MEASUREMENT OF THE VECTORS

Vectors are represented on paper (graph paper) by a simple arrow. For example, when a karateka uses wooden boards fixed in front of him at the horizontal level to break, the researcher draws an arrow toward the boards to represent the direction of the braking and ultimately this arrow could represent the magnitude of the velocity or force depending on what the researcher would like to measure. In our case, the arrow is drawn horizontally to the right.

Another arrow will represent the reaction force of the ground or the force of gravity. This arrow will be drawn vertically adding its tail to the head of the force arrow. Vectors can be added, subtracted, and multiplied. This kind of representation of the vectors uses the graphical method, which will be shown later on.

6.7 METHODS OF SOLVING VECTOR COMPONENTS

There are four methods for solving vectors and most specifically the resultant vector. The *parallelogram method* is a process of adding together two nonparallel vectors and creating two opposite and parallel sides/lines with the original vectors (Figure 6.5a and 6.5b). The resultant vector will be represented by a diagonal line drawn from the point of the unification of the two vector tails to the point of unification of the two opposite lines. The *graphical* or *geometrical method* is a process where vectors are added by using ruler, pencil, and a protractor (Figure 6.6a and 6.6b).

The *polygon method* is similar to the graphical method where each of the vectors is repositioned so that each tail coincides with the head of the

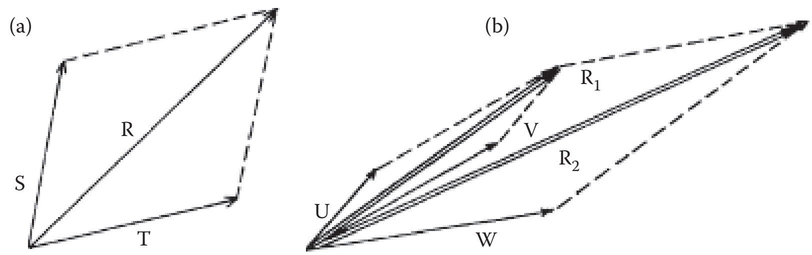


FIGURE 6.5 Represent parallelogram methods of finding the resultant vector. (a) The resultant R represents two vectors' velocity. Vectors S + T. (b) Parallelogram method for vectors U, V, and W. $R_1 = U + V$ and $R_2 = R_1 + W$. Thus, $U + V + W = R_2$.

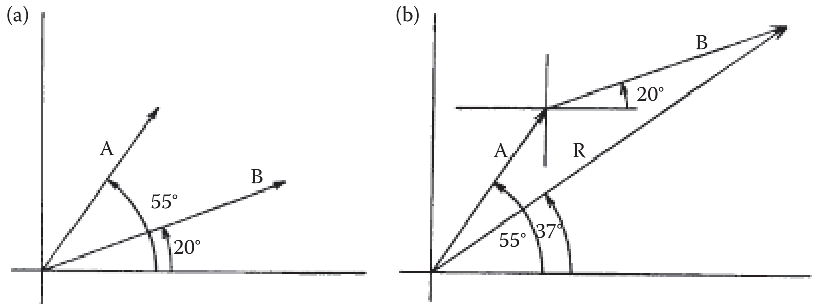


FIGURE 6.6 (a) and (b) Graphical method. Vectors A and B are added by using their magnitude and direction. The tail of B is connected to the head of A. Then the resultant is drawn. Vector A has a magnitude of 35 mm and vector B is 45 mm long. Using a ruler the resultant vector is only 77 mm because they have different directions. In the same manner, the angle for the resultant vector will be less than 55°, but more than 20°, it will be 37°. Discrepancy always exists by using a protractor, that is why trigonometric calculations are the best solution.

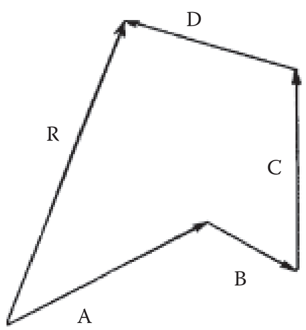


FIGURE 6.7 Polygon method R = A + B + C + D.

previous vector. The resultant vector is drawn from the tail of the first vector to the head of the last vector (Figure 6.7).

6.8 TRIGONOMETRY BASICS

Trigonometry has been used in navigation and surveying. In this book, the author will describe angles and sides of right triangles and their relations to each other, for example, how to solve right, obtuse, or acute triangles? What are trigonometric functions, inverse trigonometric functions, and so on?

Understanding and knowing basic arithmetic operations (fractions, decimals, proportions, formulas, and equations) are the prerequisite for solving trigonometric equations. The reader should have the very basic knowledge about arithmetic operations.

It has been mentioned earlier that vectors can be added, subtracted, and multiplied. Let us say we have two force vectors, for example, a 3 N and a 6 N. If they are in the same direction, then they simply add together. 3 N + 6 N = 9 N. If the vectors are in opposite direction, we subtract 6 N − 3 N = 3 N. If the vectors are at 90° to each other, for example, the 3 N is in vertical position and the 6 N is in the horizontal direction and their tails meet each other, we can use Pythagoras theorem. The resultant vector $(R_v) = \sqrt{3^2 + 6^2} = 9 + 36 = \sqrt{45} = 6.7$ N. To work out one of the angles, for example, between the resultant vector that is the diagonal line of 6.7 N and the horizontal vector of 6 N, we use one of the trigonometric function, particularly the tangent (tan): $\tan\theta = 3/6 = 0.5 \Rightarrow \theta \tan^{-1}(0.5) = 26.56°$. If we would like to find out the angle between the resultant and the vertical vector, then we simply subtract from the 90° the 26.56° and we will have the result of 63.44°. See the example of Figure 6.8. See below the trigonometric rules and the Pythagoras theorem.

The *trigonometric method* solves vector components when the horizontal and vertical components are used in the relationship of a right triangle (Figure 6.8).

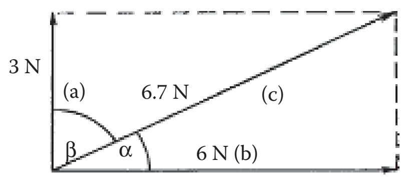


FIGURE 6.8 Trigonometric method. The dashed lines help to use also the parallelogram method using the Pythagoras theorem for the sides. For the angles, the trigonometric method is used. (a) Opposite side (leg); (b) adjacent side (leg); (c) hypotenuse; $\beta = 63.44°$; $\alpha = 26.56°$.

In trigonometry, the longest side of a right triangle is named the *hypotenuse*, and the other two sides are named the *opposite* to the angle for which the search is done and the *adjacent* where one end is attached to the end of the hypotenuse. In order to solve angles and sides representing vectors of velocity, displacement, momentum, force, and so on, we need to know the basic trigonometric functions and also the Pythagoras theorem.

When we deal with right triangles, the Pythagoras theorem states the following:

$$c^2 = \sqrt{a^2 + b^2}; \quad a^2 = \sqrt{c^2 - b^2}; \quad b^2 = \sqrt{c^2 - a^2}$$

Basically, any right triangle can be solved for all sides and for all angles if we just know: two sides of the triangle or one side and one angle of that triangle. Dealing with right angles, there is another way to find out angles. We know that all the three angles in a given right triangle give us a total of 180°. From here we know that one angle is always 90° and the sum of the other two is also 90°. Knowing one of the angle, for example, 40°, then the 40° should be subtracted from 90°, which gives us 50° for the other angle. To be more familiar with trigonometry, the reader should know some basic definitions, and those are: *trigonometric functions* specify the relationships among side lengths and interior angles of a right triangle expressed by sine (sin), cosine (cos), tangent (tan), cotangent (cot), secant (sec), and cosecant (cosec or csc).

A *trigonometric equation* is an equation consisting of trigonometric functions. *Trigonometric identity* expressing a trigonometric equation that becomes true when the variable is replaced by every permissible number. *Trigonometric ratio* is a ratio that describes a relationship between a side and an angle of a triangle. *Inverse trigonometric functions* are the inverse functions of the trigonometric functions, written $\sin^{-1}$ (arcsin), $\cos^{-1}$ (arccos), $\tan^{-1}$ (arctan), $\cot^{-1}$ (arccot), $\sec^{-1}$ (arcsec), and $\csc^{-1}$ (arccsc). Here, the author will describe the trigonometric functions using the triangle shown by Figure 6.9.

sin A = a/c expresses the ratio between the side opposite and the hypotenuse, also = cos B.

cos A = b/c expresses the ratio between the side adjacent and hypotenuse, also = sin B.

tan A = a/b expresses the ratio between the side opposite and adjacent, also = cot B.

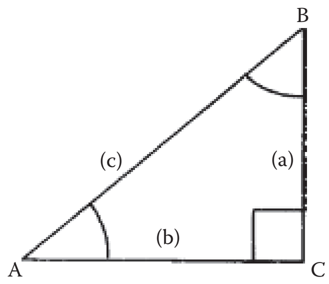


FIGURE 6.9 Here are the six trigonometric functions related to a typical right-angled triangle. The letters A, B, and C represent the angles that can also be noted by any other letters. The letter (a) represents the opposite side (leg) of angle A. The letter (b) represents the adjacent side (leg) of angle A, and is opposite to angle B. The letter (c) represents the opposite side of letter C that is named the "hypotenuse," which is always the longest side of any triangle.

cot A = b/a expresses the ratio between the side adjacent and opposite, also = tan B.

sec A = c/b expresses the ratio between the side hypotenuse and adjacent, also = csc B.

csc A = c/a expresses the ratio between the side hypotenuse and opposite, also = sec B.

The sin, cos, and tan describe the quotients of the lengths of the sides of right-angled triangles dependent on the angle A and B (see Figure 6.9). When we deal with a right-angled triangle, it is basically absolutely enough to know only the operations of sine, cosine, and tangent. From now on we will use only these three trigonometric functions to find out angles and side lengths.

For the reader to understand better the trigonometric functions about *why*, *when*, and *where* should sine, cosine, or tangent operations be used, the writer will provide some extra explanations. The reader should use Figure 6.9 for any additional explanations given by the author. The quotients of the *adjacent* (b) and *opposite* (a) with the hypotenuse (c) define the trigonometric functions sin and cos θ A. The quotient of *opposite* and *adjacent* (a) and (b) defines tan θ A.

Any right triangle can be solved for all sides and angles if we just know: two sides or one side and one angle. The known angle always must be

A or B. The author will describe two examples using the trigonometric functions related to Figure 6.9.

Example 6.1

Known: a = 33, A = 30°. Found: b = 57.09, c = 65.94, B = 60°.

Operations: To find out angle B, we subtract 90 − 30 = 60. To find out the adjacent side (b), we use tan B [60°] = b/a = b/33, tan 60° = 1.73, so 1.73 = b/33, b = 1.73 × 33, b = 57.09. We now have (a) and (b), then we use $c^2 = a^2 + b^2 = \sqrt{1089 + 3259.26} = \sqrt{4348.24} = 65.94 = (c)$.

Example 6.2

Known: a = 33, c = 67. Found: b = 58.3, A = 30°, B = 60°.

Operations: To find out the adjacent side (b), we use $b^2 = c^2 - a^2 = \sqrt{4489 - 1089} = \sqrt{3400} = 58.3 = (b)$. To find angle A, we proceed as: sin A = a/c = 33/67 = 0.49, then we take the arcsin $(\sin^{-1}) = 0.49^{-1} = 29.34°$. So angle A = rounded up to 30°. To find out angle B, subtract 90–30 = 60 = B. To find out any inverse trigonometric function, we can use a calculator by typing in the result of the sine (shown above, e.g., 0.49), then hitting on the second function first (depending on the calculator), then clicking on the sine or whatever, the trigonometric function we are looking for will give us the *angle*.

Explanations about how to solve obtuse or acute angles and examples for them will be described in Chapter 7.

Note: The author would like to specify that the study questions that will be described here will not all be specific to martial arts under this chapter.

6.9 STUDY QUESTIONS

1. A karateka kicking with his right leg upward at an angle of 50° to the horizontal has an acceleration vector ($\vec{a}$) 2 m/s^2. Find out the vertical (*y*) and horizontal (*x*) components of acceleration along the *x* and *y* axes. The acceleration vector is between *x* and the 50° grade plane.

Answer: $a_x = \cos 50° = 0.642 \times 2 = 1.284$ m/s^2. $a_y = \sin 50° = 0.766 \times 2 = 1.532$ m/s^2.

2. A similar example about a karateka who kicks in the same manner. Find out the kicking displacement. The kicking route has two components. The *x* line axis (abscissa) component has a distance of 100 cm. The *y* line axis (ordinate) component has a distance 172 cm.

   Answer: We use the Pythagoras theorem $c^2 = a^2 + b^2 = 172^2 + 100^2 = 29{,}584 + 10{,}000 = \sqrt{39584} = 198.95$ cm. (c) Represents the kicking displacement.

3. Can the velocity be zero when an object is accelerating?

   Answer: Yes, if a ball is thrown straight up in the air. At the top of the ball's path, it will have a zero velocity, but it will still be accelerating. This acceleration throughout 0 happens for an instantaneous time.

4. Two judoka compete in the open category. Judoka A has 150 kg mass weight. Judoka B exerts a force of 175 N on Judoka A. What is the acceleration if any of Judoka B?

   If Judoka B applies a small force like 5 N, can he move Judoka A?

   Answer: For $F = 175$ N, then $a = F/m = 175$ N/150 kg $= 1.16$ m/s^2 . $a = F/m = 5$ N/150 kg $= 0.033$ m/s^2. From this equation, it results that Judoka B will not be able to move Judoka A.

CHAPTER 7

Kinematics in Angular Motion

In this chapter, the author describes almost the same physical properties, characteristics regarding to rotational (*angular*) motion. Besides distance, displacement, velocity, and acceleration, which have been described in Chapter 6, other physical properties such as inertia, and different variables including tangential, centrifugal, and centripetal accelerations related to angular motion will be described in this chapter. The reader should know the following (information) facts related to angular motion. Any object/mass that is going through a uniform circular motion with a constant speed will be *accelerated* by the force driving it because a rotary motion is related to acceleration, velocity, and direction.

How should be this understood? The object/mass basically has nothing to do with speed, but has to do with velocity. Since the velocity is a *vector* that has both *magnitude* and *direction*, a change in either the magnitude or the direction constitutes a change in the velocity.

So, the conclusion of the above statement is that an object moving in a circle at constant speed is indeed accelerating. It is accelerating because the direction of the velocity vector is changing. If the magnitude of the velocity is changing, then acceleration occurs too. Putting this in simple words, the rotary motion constitutes a change in direction even if that direction is a perfect circle, and if the rotation is going on and on, it still constitutes a change of direction.

7.1 DISTANCE AND DISPLACEMENT

When a body rotates in a 2-D plane, the rotation is characterized by the fact that the rotating body (its external point) moves around the perimeter of a circle or a cylinder at the same distance from the center of rotation. The rotating body describes a certain angle that can be measured by angles or radians.

The angle is measured from the center point of the circle using the *x* axis as an arbitrary reference line that moves around the path of the circle. The end point of *x* should coincide with the initial point of the particle of the body, and then the measurement will end at the end point of the particle rotating on the circle. This path on the circle is named as *angular displacement*. What is then the *distance* in a circular motion, and how is it measured? The *distance* in angular rotation in fact represents a distance separation between two objects observed from a location different from either of these two objects. In other words, *angular distance* is thus synonymous to the angle itself.

When we deal with movements of human beings, the rotations of the human segments and the entire body describes absolutely only rotations and no rectilinear movements at all. Linear movements of humans are acceptable theoretically. How should this be understood? Imagine if you approach or depart one of your body segments such as flexion or extension of your forearm, the rotation will occur at the center point of the rotation, which is the joint of those body segments. When you flicker with one of your finger to move a small object from the table, there is a rotary movement between two phalanges. Recall that linear movements of human beings are acceptable theoretically or can be considered only when the human body segment is related to an object or scope.

For instance, walking is related to the ground or to the arrival point, so the body is walking using a rectilinear movement. In this case, we can talk about linear speed, distance, or even linear acceleration and so on. The measurement of the distance/displacement in 2-D plane can be done to the positive direction, which is counterclockwise, or negative direction, which is clockwise. Both measurements usually start from the *x* axis line. Figures 7.1 and 7.2 show the measurement of the angular distance and displacement.

The equation for the displacement is the following: $s = r \cdot \theta$ or $\theta = s/r$. The unit of the radian represents the dimensionless measure of the ratio of the circle's arc length to its radius. The author will further describe radians, angles, circumference, radius, pi (π), and other mathematical signs and expressions (see Section 7.2).

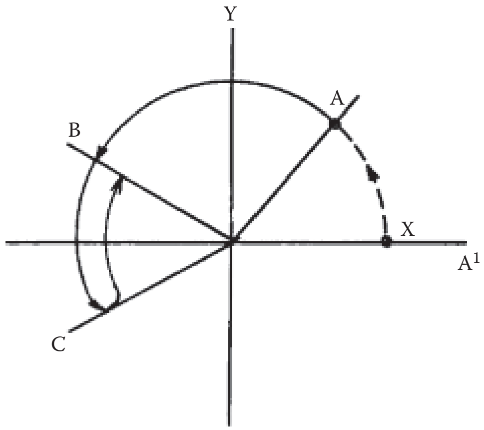


FIGURE 7.1 The angular distance is measured from point A or point A[1] throughout point B, point C, and returning to point B as the terminal site. The addition of the angular distance is made θ d = A(A[1]) + B + C.

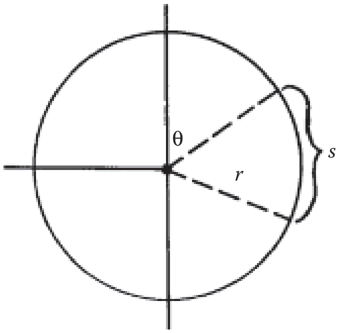


FIGURE 7.2 The angular displacement is measured by using radians rather than degrees. The arc length (s) equals of the length of the radius (r) of the circle and the subtended central angle (θ) equal 1 radian (rad).

A body can change its movement from a translation movement to a rotational movement and vice versa. For instance, from martial arts of karate, a simple direct punch of the forearm where the fist moves through a *straight line* approximately for a distance of 45–50 cm, and then the fist will *rotate* from supine to prone position again for a distance of approximately 12–15 cm when the fist should reach the target.

7.2 CIRCLES, QUADRANTS, AND THEIR ANGLES

When we speak in general about martial arts, it is well known that almost all the motions are in effect within 3-D in space, also describing a circular

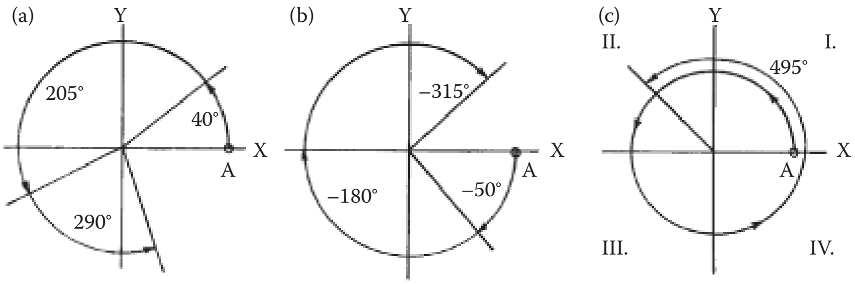


FIGURE 7.3 (a) Counterclockwise (positive) direction of a circle. (b) Clockwise (negative) direction of a circle. (c) Quadrants of a circle (I, II, III, IV).

motion following a circular path the rotation that describes an angle is measured by degrees or by radians. Usually the circle is divided into four parts named *quadrants* by using only the axis of x and y. Using the x and y axes, the measurement is 2-D in space. An angle with its initial side on the x axis is said to be in *standard position*. Angles that are in standard position are said to be *quadrantal* if their terminal side coincides with a coordinate axis. A circle has four quadrant positions. Each quadrant measures 90° angle. Therefore, a circle has 360° angle. Figure 7.3a–c shows the quadrants of circle and the negative or positive directions measured by angles.

Point A represents a reference point. From this point, the calculation of the angles are counted to be counterclockwise or clockwise (–) direction. Figure 7.3b represents a full circle of 360° (–45°) in a positive direction measured from point A toward the (x) axis all around. Figure 7.3c shows a counterclockwise direction of a 495° route.

In human mechanics, we sometimes have to use different calculation methods using a circle as a reference for the joint's angular motions. In this case, it is important to know the geometric terminology and symbols such as circumference, revolution, diameter, radius, tangent, radian, and degrees. The author assumes that the reader knows these terminologies. The following table serves us for fast calculations of the revolutions, radians, and degrees:

Revolutions	**Radians**	**Degrees**
1	360/2 π (or 6.28 rad)	360°
0.5	180/1 π (or 3.14 rad)	180°
0.25	90/0.5 π (or 1.57 rad)	90°
2	720/4 π (or 12.56 rad)	720°

Note: 1 radian (rad) = 57.3°, 360° = 6.28 rad, π = 3.14, circumference (C) = $2\pi r$, r = radius.

7.3 SPEED, VELOCITY, AND ACCELERATION

The *average angular speed* (ω) tells us how many complete rotations or revolutions are there per unit of time. More precisely, the angular speed tells us the change in angle per unit of time, which is measured in radians/s. Angular speed can also be measured in degrees, for example, 360°/s. Even if the term *angular speed* is equivalent to rotational velocity, there is a difference, which is the rotation (revolution) per minute, for example, 60 rpm. Angular speed represents the magnitude of angular velocity.

The *angular velocity*, whose sign is also a Greek letter omega (ω), is a vector quantity; that is why in most physics books or other books, the authors use the terms *angular velocity* and *angular speed* interchangeably. The magnitude of angular velocity can be described in two terms. One is the *average angular velocity*, which represents the angular displacement of an object between two points of an angle such as θ_1 and θ_2 at the time intervals t_1 and t_2, respectively.

Then, the equation for *average angular velocity* is $\bar{\omega} = (\theta_2 - \theta_1/t_2 - t_1) = (\Delta\theta/\Delta t)$; the other term for the magnitude is the *instantaneous angular velocity*, which is the limit of the magnitude ratio as Δt approaches 0. The formula is: $\omega = \lim$ as $\Delta t \rightarrow 0$ $\Delta\theta/\Delta t = d\theta/dt$, both $\bar{\omega}$ and ω being measured in m/s. To find out the *average angular acceleration* and the *instantaneous angular acceleration*, we proceed in an analogous fashion to linear velocities and accelerations. The *average angular acceleration* ($\bar{\alpha}$) of a rotating body in the interval from t_1 to t_2 can be defined using the following formula, where ω represents the instantaneous angular velocities.

The formula for *average angular acceleration* $\bar{\alpha} = \omega_2 - \omega_1/t_2 - t_1 = \Delta\omega/\Delta t$, and the *instantaneous angular acceleration* $\alpha = \lim$ as $\Delta t \rightarrow 0$ $\Delta\omega/\Delta t = d\omega/dt$, both $\bar{\alpha}$ and α being measured in rad/s^2.

Speaking about angular motion, we should mention two different and important accelerations. One of these is the so-called *radial component* of the linear acceleration that is named *radial acceleration*, also called *centripetal acceleration*. This component acts inwardly toward the center of rotation. The mathematical equation is $a_r = v^2/r$, where v is the linear velocity and r is the length of the radius of rotation. The formula can also be written as $\omega^2 r$.

The second kind of component of the acceleration is named the *tangential acceleration* that is directed along a tangent to the path of the body traveling in angular motion that indicates change in linear speed: $a_t = v_2 - v_1/t$, where a_t is the tangential acceleration, v_2 is the final time of the linear velocity, and t is the time interval over which the body is assessed, simply m/s^2.

7.4 STUDY QUESTIONS

1. A karateka stands in front stance *(Zenkutsu-dachi)* and executes a roundhouse kick at the middle level of the opponent. He increases his speed from "0" radian to 3 rad/s in a time of 0.5 s. What is his angular acceleration? We use the equation for angular acceleration (α) = rad/s^2. One radian (rad) = 57.3°. If we multiply $57.3 \times 6 = 343.8°$, which means he can turn almost 360° in 1 s.

   Answer: 3 – 0/0.5 s = 3/0.5 = 6 rad/s^2.

2. As in the previous example, the karateka leg from the coxo-femoral joint to the toes of the kicking leg has a radius of about 110 cm and a speed of 0.5 s. What is his centripetal acceleration? $a = v^2/r$.

   Answer: 0.5^2/110 cm = 0.25/1.1 m = 0.22 m/s^2.

CHAPTER 8

Kinetics in Linear Motion

8.1 INERTIA, MASS, WEIGHT, AND FORCE

The four words inertia, mass, weight, and force are very closely related to each other. *Inertia* is the property of mass that causes it to resist any change in its motion or its state of stillness. Thus, a body at rest remains at rest unless it is acted upon by an external force and the body in motion continues to move at constant speed in a straight line unless acted upon by an external force. This statement represents Newton's first law of motion.

The *mass* is a measure of a body's inertia, that is, its resistance to acceleration. The mass of an object is constant everywhere. The *weight* is a force of attraction exerted on an object by the gravitational pull of the Earth. Weight on Earth has different values depending on the place where the object is. Being a force, weight should be measured in Newton (N), and a body of mass will have a weight = $m \cdot g$, where (g) is the acceleration of free fall or gravity (9.80665 m/s^2). The kilogram (kg) is an SI base unit of mass. From here results that a mass of 1 kg = 9.8 m/s^2. A man of 70 kg mass $\times$ 9.8 m/s^2 will have 686 Newton force.

8.2 FORCES

Recall that kinetics deal with motion that includes the forces that cause the motion. The physical property of the *force*, perhaps, is the most important between other physical properties, such as momentum, impulse, energy,

velocity, and so on, which are related to objects in static positions or dynamic motions, including humans and animals alike. *Force* is described as the effect one object has on another, which can alter the state of a matter by pushing, pulling, twisting, sliding, and so on, and this effect of the force (F) is the product of a mass and its acceleration $F = m \cdot a$.

There are many different kinds of forces such as internal forces; for example, in biomechanics, a muscle contraction produces *internal forces* that move a segment of the body. *External forces* represent actions on the system of the human body such as a pushing, pulling, or twisting force or even push of the wind. The gravity and inertial forces have been described in Chapter 6.

Force is a vector quantity that includes magnitude and direction. The force of action usually includes a point and a line of application. The force vector is represented by an arrow, usually a straight line from the origin of the force that shows the direction of the force and the length of the arrow represents the magnitude of the force. Other vector quantities are velocity, acceleration, momentum, torque, and impulse. In the human body, the force is represented by the skeletal muscle. A specification that is important to be mentioned here is that muscles can execute only *pulling actions*. To better understand the pulling actions of the muscles, here is the explanation: When you pull a cart, you say there is a pulling action of the biceps muscle. But when you push a table, you probably will say there is a pushing action. It is not! You have to think about your muscle's actions again. In this case, the triceps muscle pulls the forearm for the extension position that results in a pulling action of the triceps muscle even if your arms are extended. For a popular explanation you should say my body is pushing an object or better the object will depart from your body.

8.2.1 Force of Gravity

For a freely falling object, the only force is the force due to *gravity* (commonly called the weight). If the only force acting on an object is its weight, we find that the acceleration is independent of the mass of the object. The gravitational force is a vector that always points straight down. Weight is the magnitude (or size) of the gravitational force acting on an object; since weight is a magnitude of a vector, it is always a positive quantity, weight (w) $= m \cdot g$.

8.2.2 Specification of Forces

When a biomechanist wants to find out the forces acting on a body, he uses the so-called *rigid body model* analysis, which should include different

forces acting on the body, direction of those forces, and their effect on the body in case. A rigid body represents an object that tends not to change shape when forces are applied to it. We know that the human body is not rigid at all. Different body parts/segments are linked together with joint systems. Also, we know that each segment has a fixed mass with a CoM located at a fixed point.

From this assertion, the biomechanist considers the body as a rigid link composed of stick figures. By having this stick figure we can use the so-called sticks as vectors with their directions and we can use resultants by using trigonometry and different calculations to find out the forces.

Bodies that walk, run, swim, kick, rotate, and so on usually have the following forces: grand reaction forces (GRF), net force, normal force, body weight, gravity, friction, air resistance, and impulsive forces. These forces are external forces and they are in effect on the body in a static position or in dynamic motion. Let us succinctly discuss each of them. Figure 8.1 shows a *free body diagram (FBD)* or a so-called (*rigid body model*) with forces acting on it.

The *ground reaction force* is a resultant reaction force equal and opposite to the applied force on the supporting surface. The *net force* is a vector sum of all forces acting at a joint. The net force acting on a static body is zero. *Normal (reaction) force* is a component of a force that is acting perpendicular to the surface and the direction is always directed upwards. The opposing force is usually the weight of the body.

If a skier slides down a hill, his weight acts perpendicular down to the inclined surface. The normal reaction force is also perpendicular to the surface but acts in the opposite direction. The normal reaction force in fact represents the classical Newton's third law of motion that states that for every action there is an equal and opposite reaction. Therefore, when one object exerts a force on another, there will be an equal force exerted in the opposite direction by the second object on the first.

Recall Newton's first law of motion, which states that a body continues in a state of rest or uniform motion in a straight line unless it is acted upon by external forces.

The reader can ask why this law does not apply when a body continues its motion on a rotary path. The reader should know that any change of direction even if that direction is always on the same path, such as a complete rotary circle motion, the object will accelerate.

This acceleration is directed toward the center of the circle, with a magnitude equal to $a = v^2/r$, where v is the velocity of the body or particle

and r is the radius of the circle. The acceleration is called the *centripetal* or *radial acceleration*. The reason for the centripetal acceleration is the *centripetal force* acting on the body. This force is directed toward the center of the circle, and can be described from Newton's second law: $F = m \cdot a = m \cdot v^2/r$.

We know about force which a body possesses that its effect is an interaction with another body. Humans experience interaction of different forces such as gravitational, physical, mechanical, electrical, and so on.

The relationship between force and acceleration as given by Newton's second law is valid to a motion if it is measured in a certain type of reference system called *inertial frame of reference* (IFR). An IFR is the one, in which Newton's laws of motion are valid. The IFR is a zero accelerated frame of reference.

Understanding velocity and force as vector quantities, the following will be described. When an object rotates around a fixed axis and moving with a constant speed, the object's velocity vector is constant in magnitude but varies in direction.

Figure 8.1 represents an *FBD* with different forces acting on the body. The tiny circles represent the major axes and the lines represent the links of the kinematic chain. F_b is the force of the blocking arm (this is not a force that acts on the body/sketch), F_i is the force of the impact, CoM is

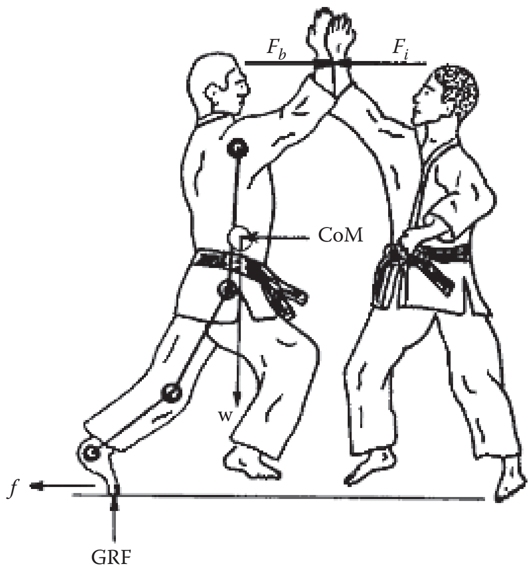


FIGURE 8.1 Free body diagram (FBD).

the center of mass, w is the body weight + g (gravity), f is the friction force, and GRF is the grand reaction force.

The top circle represents the shoulder (scapulo-humeral) joint and the kinematic chain leads to the coxofemoral joint, to the knee joint, to the ankle, and finally to the toes, which are not represented here.

People think that because speed is constant for such a motion there is no change in velocity, and therefore there is no acceleration at all. People also think that acceleration has to do with speed and not with velocity. This is wrong. The fact is that an accelerating object is an object that is changing its velocity. And because velocity is a vector that has both magnitude and direction, a change in either the magnitude or the direction constitutes a change in velocity.

Having stated these facts we can conclude certainly that an object moving in a circle at constant speed is indeed accelerating. It is accelerating because the direction of the velocity vector is changing. The result of these changes is the effect of the force. These facts are supposed to be described in Chapter 7. Because these changes are related to force, that is why we describe it under the kinetics section.

8.2.3 Calculation of Different Forces

Recall that internal forces are generated internally by the system (muscle force), which produces body movement related to the body system. Internal forces that facilitate a movement such as flexion of the forearm are in fact related to isometric or isotonic muscle contraction. Let us take again the example of the flexion of the forearm. In case of isometric contraction, when we speak about force, the involvement of the action is twofold:

1. The muscle contracts and tension develops but no change in the length of the muscle and no movement of the body part happen.
2. The muscle contracts against an external object or against an opposing arm of the system and tension develops with no change in the length of the muscle; it is still an isometric contraction. However, in this case, isometric contraction meets an external force. The isometric contraction is related to the thermodynamic process.

In both cases (a) and (b), there is an increased tension by using the internal energy. There is no mechanical work that is equal to force and

displacement. By using the internal energy there will be a decrease in the amount of the contractile protein molecules found in the muscle tissue. Hence, there will be muscle degradation.

External forces are those exerted by different objects/bodies outside the previously specified system. External forces cause movement of the body or the object in case. In biomechanics and in martial arts, we take into consideration almost exclusively the external forces. Let us examine the external forces shown in Figure 8.1 using the FBD.

To calculate the GRF we need to know the weight and the gravity. GRF = $w \cdot g$. But this calculation is good only if the total CoM is at the lower abdomen part of the body. If the athlete runs, he has contact with the ground only with one leg; then the CoM is not in the middle of the body and in this case the calculation is different from the aforementioned formula.

8.3 FRICTION

The force of friction (f) is proportional to the force pressing two surfaces together. The force of friction always opposes any motion. There are different *types of friction*, such as *static* and *kinetic*, which includes the sliding and rolling frictions. An object that does not move with respect to the surface on which it rests is subjected to static friction.

In martial arts, the dominant force of friction is the sliding force. This is a counterforce of a pushing action against an opponent. For example, a wrestler's leg force pushes the opponent's body; it is opposed by a counterforce that acts backwards of the pushing force of the wrestler, and this is the friction force.

Imagine two judoka ready to grab each other's kimono. At this time, there is much pushing involved for the action of grabbing (*Kumi-kata*) of the kimono. Judoka A on the left side pulls Judoka B on the right side. Let us pretend the magnitude of the limiting friction force is 150 N. If Judoka A exerts a horizontal force of only 110 N against Judoka B, the magnitude of the friction will also be 110 N and Judoka A will not be able to move Judoka B horizontally.

If Judoka A increases his pulling force to 150 N, he will still not be able to pull Judoka B; this is because the magnitude of the limiting friction force equals Judoka A's pulling force. If Judoka A is able to pull Judoka B with a force over the limiting friction force of the opponent, for example, pulling with 160 N, then the limiting friction force will not be able to sustain the effect of the friction force. Judoka B will be moved.

It is easiest when we use an example from different objects other than a human body because the friction force can be calculated easier than in a case of punching or kicking by a human.

Friction forces (f) between two bodies can be altered by (a) moving on slippery surfaces and (b) altering the forces that hold the two surfaces together. To find out the limiting friction force, we use the following formula:

For static friction, $(f_S) = (\mu_S)F_N$. μ_S represents the coefficient of static friction and F_N represents the magnitude of the normal force. For kinetic friction, $f_K = (\mu_K)F_N$. f_K represents the kinetic friction and μ_K represents the coefficient of kinetic friction.

In both formulas, the coefficient of friction (μ) represents a unitless number indicating the mechanical or molecular interaction between two surfaces in contact. The lower the coefficient of friction, the easier it is for two surfaces to slide over each other.

Calculating the frictional forces, we always use a *coefficient of friction*. In physics, science, and mechanical books, we can find tables that show the coefficient of friction of different materials (see Table 8.1). The sign of the coefficient of friction is the Greek letter μ (mu). Usually μ is less than 1. The friction force has three principles:

1. The friction between two surfaces is proportional to the force that presses the two surfaces together, for example, the larger the mass, the more difficult it is to slide the mass.

TABLE 8.1 Different Values of the Coefficient of Friction

Material Sliding Over	Base Material	Static	Kinetic	Lubricated
Steel	Steel	μ_s 0.80	μ_k 0.58	0.16
Teflon	Teflon	0.04	0.04	
Teflon	Steel	0.20	0.04	
Aluminum	Steel	0.61		
Copper	Steel	0.53		
Brass	Steel	0.51		
Zinc	Cast iron	1.85		
Copper	Cast iron	0.05		
Glass	Glass	0.94		
Copper	Glass	0.68		
Rubber	Concrete/wet	0.30		
Rubber	Concrete/dry	1.00		
Rubber	Rubber	1.16	~1.02	
Wood	Wood	0.28	0.17	

2. The friction between two surfaces depends upon the nature of their surfaces of contact.

3. The friction between two surfaces is independent of the area of the surfaces of contact. In this case, there is no change of friction force whether a man stands on one foot, on both feet, or even on the toes. The friction force is dependent on the object mass.

Let us take a simple example for kinetic sliding friction. Figure 8.2a represents a "large outer reap—throw" *O-soto-gari*. Here, the judoka on the left side of the figure tries with his right leg (T-r) to hook his opponent's right leg. The right side of the figure represents a beginning "floating hip throw" *Uki-goshi*. The attacker (*Tori*) uses his left hand by grabbing the kimono sleeve of the defender. The attacker's right arm can grab the defender's left collar.

Every effort made by the Tori is to guide his force to Uke's right, and not only to sweep the right leg of the Uke, but to simultaneously pull and twist the Uke's right arm, off-balancing the Uke's stability.

In Figure 8.2a and 8.2b, the defender (*Uke*) tries to move his body from the opponent by holding the body completely perpendicular to the ground (see Nr.1, Nr.2, and Nr.6 in both figures). By doing so, the defender will have the best chance to press with more force against the ground, by holding the CoM at the lower abdomen level of his body.

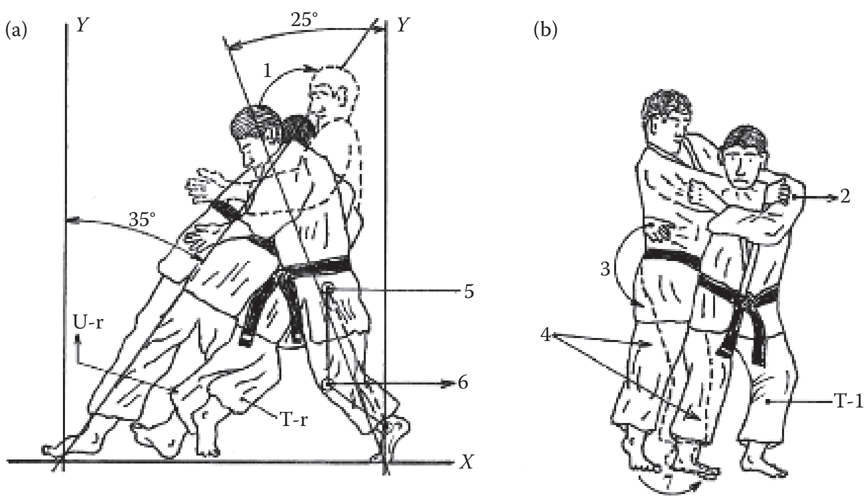


FIGURE 8.2 (a) *O-soto-gari* (large outer reap). (b) *Uki-goshi* (floating hip throw).

In this way, the defender(s) can create a large coefficient of friction. The larger the coefficient of friction, the more difficult it will be for the attacker (*Tori*) to throw his opponent.

Nr.1 represents the *Uke's* head movement (straightening the body).

Nr.2 represents the *Uke's* right arm pushing the *Tori's* shoulder.

Nr.3 represents the throwing direction.

Nr.4 represents the *Uke's* right leg movement.

Nr.5 represents the *Uke's* coxofemoral articulation.

Nr.6 represents the *Uke's* knee movement/direction by straightening the entire left leg.

Nr.7 represents the *Uke's* right foot forward movement.

T-l represent the *Tori's* left leg.

T-r represents the *Tori's* right leg.

U-r represents the *Uke's* right leg.

To calculate the friction forces of these two figures, here are the formulas.

In Figure 8.2a, both judokas have 70 kg mass. The attacker judoka on the left side noted as T-r (right leg) tries to execute a throwing technique against the defender. The floor (*Tatami*) is considered to be of rubber type. The static coefficient of friction $\mu_S = 1.16$ and the coefficient of kinetic friction $\mu_K = 1.02$. Question:

1. Find out how much force is required to start the moving (throwing) process?
2. Find out how much force is required to keep it in motion?

These two coefficients were taken from Table 8.1. The author chose the rubber on rubber sliding materials. This technique is relatively simple; however, because the different forces such as the attacker's force (CoM); his both feet friction forces, especially the left one; the defender's similar forces; the arm forces of both judokas; and finally the attacking and opposing angles make it very difficult to establish a common and sure way

to tackle the problem to be solved for the friction forces. The author tried some very simplistic but correct way to solve the problem, which is to use the basic equation of the kinetic friction forces.

Problem-solving Nr.1a for Figure 8.2a. When the attacker moves to take down the defender, his body inclined to approximately 35°, we can use this degree to find out the frictional force (f); however, his inclined angle is only temporary, because as much he succeed to take down his opponent this angle will be much larger (because a more front inclination), so in this case we have to use another angle. Readers should realize that the 35° pushing angle force is not similar to when you push a heavy box on a flat or an inclined surface where the *angle remains unchanged*.

Nr.1b. If we choose the angle of the defender, which is 25°, then we can encounter the same problem. The defender only has 25° angle, probably because the attacker is much stronger or he is pushed already, or better said the pushing force is still in progress. Because the angle is changing back and forth, we should use another angle? The defender will lose his balance if he will be pushed backwards over the vertical "Y" line, and he will fall down.

Problem-solving Nr.2. The best and probably the correct way for this technique to look at the attacker's forces; when the attacker directs his force of throw to the CoM of the defender, the angles, especially the vertical line angle, are not important and the calculation is as follows:

Answer for (a): mass $(m) = (70\text{ kg})(9.8\text{ m/s}^2) = 686\text{ N}$; $\mu_S = (1.16)(686\text{ N}) = 795.76\text{ N}$.

Answer for (b): $\mu_K = 1.02 \times 686 = 699.72\text{ N}$. *The reader should note that there is a fine line between the static and the kinetic friction forces.* At this moment (Figure 8.2a) of the mowing/throwing process, we have to deal with the static friction force; however, when the attacker managed to pick up the defender's right leg, practically no kinetic friction acts on his picked-up leg. The real kinetic friction forces will act on both (attacker and defender) left feet because those are in contact with the ground and those are moving and slipping on the ground.

We should count on the defender's left foot and not the attacker's left foot. The reader can decide if he wants to use, for example, the angle of 25° related to "Y" axis. The GRF on the defender, which inclined at 25° with the normal force F_N will show the following equations: $F_{\max} = \mu_S(m \cdot g \cos 30)$. A similar way of calculating the kinetic frictional force $F_{\max} = \mu_K(m \cdot g \cos 30)$.

From Figure 8.2b, calculating the static friction force is simple. $\mu_S = 1.16 \times 686 = 795.76\text{ N}$. The static frictional force will exist for a longer time, perhaps, 2–4 s. Once the attacker grabbed the defender by the waist,

the defender can delete the throwing action of the attacker by pushing the attacker's left shoulder (see Nr.2 arrow). To stop the throwing action definitively, the defender can move his right leg forward in front of the attacker's right leg (see Nr.7 arrow).

Note: In Figure 8.2a, the attacker will have difficulty in throwing the defender if he is straightening his left leg (see Nr.6 arrow) and erecting his head to the vertical (see Nr.1 arrow), which has been explained before.

8.4 MOMENTUM

Momentum represents the amount of motion possessed by a moving object. It is a vector quantity having magnitude and direction. It is also a measure of the energy what an object contains due to its motion. Because momentum is conserved in any collision, it also measures the amount of energy that can be transferred to another object. Momentum and kinetic energy are similar but the fundamental difference between them is that momentum is a vector that is proportional to speed while kinetic energy is a scalar proportional to velocity squared.

Newton's second law of *acceleration* states that when a body is acted on by a *force*, it results in a change in *momentum* that takes place in the direction in which the force is applied, and is proportional to the force causing it, and inversely proportional to its mass.

Change in velocity means acceleration or deceleration by a force that was applied. Thus, a body's momentum can be changed by altering either its mass or its velocity.

The equation of the linear momentum is $p = m \cdot v$ or kg · m/s. $\Delta p/\Delta t = F = m \cdot \Delta v/\Delta t = m \cdot a$. In the absence of F, $\Delta p = 0$ or p = constant. Newton's third law can also be used in relation to momentum. In this case, the force of the action is equal and opposite to the reaction force and the rate of change in momentum produced by the action of the force on the body is equal and opposite to the rate of change of momentum produced by the reaction force on the other body. So, in this case, the change of momentum created by the first object will result in the same momentum changes by the second object.

8.5 IMPULSIVE FORCES, COLLISIONS (IMPACT)

The effect of the applied force and the time over which the force is applied is called *impulsive force* or just *impulse*. These impulsive forces occur when two or more objects collide. In sport, there are many examples. A tennis

player or golf player hits the ball, a karateka hits an opponent or hits the punching bag, and a fencer executes a straight cut on the mask of the opponent and so on. The equation of the impulse is $J = F\Delta t$ or N · s.

In physics, we talk about the impulsive force for a given time interval, which is equal to the change in momentum produced over that time interval, that is, $J = m(v_f - v_i)$, where m is the mass, v_f represents the final velocity, and v_i represents the initial velocity. This conception of the change in momentum is derived from Newton's second law and is known in sports as the *impulse–momentum relationship.*

There are many different kinds of impulses in science. In sports, there are three different kinds of impulses:

1. *Controlled impulse* refers to the muscle effort and bone leverage, for example, striking or kicking.
2. *Transmitted impulse* occurs when, for example, a karateka is about to take off for a flying side kick. The take-off leg acts against the floor, but the magnitude and direction of impulse is determined by the free arms and leg, and not through the take-off leg.
3. *Physiological impulse* includes the nervous impulse initiated by different agents and conditions: sound, light, taste, smell, mechanical, electrical, and so on. In our case, we will refer to the first two impulses. It is important to explain the difference between *impulse* and *impact.*

The impulse ($F \times$ time) is not a force (N), it is an integral of force over time. The impact is a force (N). Impact deals with force and of course force deals with acceleration. The impact force is usually extremely short. The impact force has the same unit as the force ($F = m \cdot a$). Impulse deals with momentum, which in turn deals with velocity. The impulse unit is kg · m/s.

Impulse can be increased by adding more force to the impact or by increasing the delivery time before the impact. There is a complete inverse proportionality about the force and time used before the collision. When a large force is used, usually the time must be extremely short or when the force is reduced, then the time delivery for the force must be much longer.

A body that is about to collide with another body does not change its physical shape. At the time of collision, one of the bodies or both can change their physical shape; however, they can regain their initial shape or form after the collision. In this case, we speak about *elasticity* of the object(s).

A collision in which the total kinetic energy after the collision is less than that before the collision is called an *inelastic collision*. To be more explicit, the body or bodies will change their physical shape. Example includes a car crash or when two bodies stick together after the collision, for example, a sticky material thrown against the wall.

A collision in which the total kinetic energy of a system will remain the same after the collision is called *elastic collision*. To be more explicit, the bodies will deflect each other with no physical change of shape. An example is when two billiard balls collide.

The body has the tendency to return to its normal shape once it has been deformed, that is, its elasticity differs from one body to another. Some return very quickly to their original shape, while others do so less quickly. Because there is no way of directly calculating the elasticity of a body, it is necessary to rely on the different experiment results to predict the outcome of any given impact.

Newton formulated an empirical law, *Newton's law of impact,* which states that if two bodies move toward one another along the same straight line, the difference between their velocities before the impact is proportional to the difference between their velocities after the impact. In order to correctly calculate the velocities before and after the impact, there is a term *coefficient of restitution*, which must be used in our calculation.

The coefficient of restitution (e) or COR is an indicator of elasticity of an object reflecting the ability of the object to return to its original shape once deformed, measured by the ratio of the impulse of rebound to the impulse of impact. This coefficient has a value between "1" and "0." The value of "1" indicates an elastic collision. The value toward "0" indicates an inelastic collision. To be more precise, the COR is an indicator of impact resistance.

The equation could be $v_1 - v_2 = -e(u_1 - u_2)$ or $v_1 - v_2/u_1 - u_2 = -e$, where v_1 and v_2 represent the velocities immediately after impact of bodies 1 and 2; u_1 and u_2 are their respective velocities immediately before impact; and e is a constant known as the coefficient of restitution.

In martial arts, the impacts are almost 100% elastic collisions, when a strike hit a hard target (like the head). The only inelastic collision that could happen is when one or both of the combatants will have some broken bones. All collisions involve momentum $p = (m \cdot v)$ and impulse $J = (F \cdot t)$. In order to understand the importance of these terms, here are some examples with explanations.

In throwing objects such as tennis ball, football, javelin, discus, baseball, golf ball, and so on, the speed/velocity is important for gaining distance.

Using the impulsive force, the athlete should use a prolonged time in order to gain distance, but in karate particularly, speed is not important for gaining distance but it is extremely important to reach the target in the shortest time as possible.

In track and field and also in baseball, to successfully gain the distance, the athlete uses his hip power first, and then continuously uses the torso, the shoulder, and the arm finally to liberate the object. However, the hip is a pretty rigid entity and cannot turn more than 45° angle or a little bit more (see Chapter 4, Figure 4.3). That is why in order to gain speed, the athlete prolongs the time for force liberation, for example, for discus throwing, the athlete spinning his body and the baseball hitter executing the hit by a follow-through.

The importance of creating as large an impulse as possible is evident in the case of a baseball pitcher. The pitcher uses the longest time over which to apply the force to the ball before releasing it. Another example in baseball is the hitter who is often encouraged to follow-through when striking the ball. We can find the same examples in tennis or golf as well.

High-speed films of the collision between bats/rackets and ball have shown that the act of following through serves to increase the time over which collision occurs. Surprisingly, this prolonged time for hitting favors not the force of the impact between the ball and the bat rather the change velocity of the ball to gain distance.

Karate, however, is a different story. The karateka must favor force over time. Where the force is larger and the time is shorter, the impact will be devastating, especially when the punching arm may bounce off the target like a whip on a heavier object. The withdrawn arm or in karate term, *Snap-punch* is which creates a more devastating effect on the opponent. See the time and force relations that are inversely proportional. Table 8.2 will demonstrate this.

Let us say we need to have 100 N for the maximal effect of a blow/throw/push.

TABLE 8.2 Force, Time, and Impulse Relationship

F ×	***t*** =	***J***
Force (N)	**Time Required (s)**	**Acquired Impulse**
100	1	100 units (max. impulse)
50	2	100 units (max. impulse)
25	4	100 units (max. impulse)
1	100	100 units (max. impulse)

8.6 ENERGY, WORK, AND POWER

8.6.1 Energy

In our daily life, we often hear talk about energy. Do you say to yourself "I have no energy to finish the job or I need more energy to be able to reach a destination when you are walking on a hill?" The energy is the ability to do work.

It is difficult to define energy in precise terms of shape, mass, or size. Rather, the energy suggests a dynamic state related to a condition of change because the presence of energy is revealed only when a change has taken place.

There are two kinds of *energy: potential* and *kinetic energy.* The potential energy is a stored energy in a body or system. The kinetic energy can be described as the capacity to do work by virtue of the body's motion. Where is a motion, such as a wind blow, a waterfall, a karateka kick, or the chemical composition of a body with its atoms and molecules that are in motion, there is a kinetic energy (e.g., heat energy). The kinetic energy comes from the potential (stored) energy.

We know that there are many different kinds of energy such as chemical, electrical, light, wind, thermonuclear, water, and mechanical energy. According to the law of thermodynamics (*conservation of energy*), which states that in any system not involving nuclear reactions or velocities approaching the velocity of light, *energy cannot be created or destroyed* but can be lost. An athlete can lose or deplete his energy if he does not adequately supply it by means of meal, drink, or rest.

Let us analyze the potential energy a little bit more, noted with PE or U. U also represents work. We can see or realize that when an object has been moved to a certain distance and it has the tendency to return to its original position due to a force, which is also often called a *restoring force*, it represents a stored energy called the potential energy. For example, a stretched spring has the tendency to return to its original position due to potential energy. Another example is that when a weight is lifted up to a certain height, the force of gravity will try to bring it back to its original position due to the *gravitational potential energy.*

The driving force that can affect an object's gravitational potential energy is as stated before the restoring force and the object's height relative to some reference point, its mass, and strength of the gravitational field it is in. In this case, the equation is $PE = m \cdot g \cdot h$, where m is the mass, g is the gravity, and h is the height or altitude of the gravitated object. The change in potential energy $\Delta PE = m \cdot g \cdot \Delta h$.

There are many different types of potential energies, each associated with a particular type of force, for example, gravitational potential energy, elastic, chemical, electrodynamics, electrical, nuclear, and thermal *PE*. Interestingly, potential energy can be easily converted into kinetic energy and vice versa by just a simple movement. For example, consider an object on the floor. By picking up the object from the floor, the gravitational force does negative work. If the object returned back to the floor, the work by the gravitational force will be positive and at this time the *PE* accelerates the object and is converted into kinetic energy (*KE*).

For a simple calculation of *PE*, we can use the example given in Chapter 6 (Figure 6.2). We calculated the velocity and the distance of a judoka thrown by his opponent. We can easily calculate the *PE* of the judoka who is the thrower (*Tori*), knowing only the mass and the distance from where the judoka will be thrown.

The mass of the judoka = 70 kg and the distance (h) = 160 cm; thus, $PE = m \cdot g \cdot h = 70\text{ kg} \times 9.8\text{ m/s}^2 \times 1.6\text{ m} = 1097.6\text{ J}$ or $\text{N} \cdot \text{m}$. The joule is the work done by a 1 Newton (N) force that moves an object through 1 m in the direction of the force.

Besides gravitational potential energy, the elastic potential energy is important; however, we cannot use it in martial arts, except in archery (*Kyudo in Japanese*). The elastic potential energy (PE_E) of the string of the bow = $\lambda x^2/2l$, where the Greek letter (lambda λ) is the *module of elasticity* under the extension of x (in physics energy extension) and l is the string length pulled to a certain distance.

In martial arts, we deal mostly with kinetic energy (*KE*). Recall that kinetic energy is the energy of motion. This motion can be done in any direction from one point to another point. The kinetic energy can be translational, rotational, and vibrational. In this chapter, we focus on the translational *KE*. The equation is: $KE = 1/2\ m \cdot v^2$, where m represents the mass and v the velocity squared. Kinetic energy is a scalar quantity that has magnitude and no direction. The kinetic energy is totally described by magnitude alone. The method to measure kinetic energy is the same as that for the potential energy, whose unit is the joule (J).

Let us take an example from karate for kinetic energy. Calculate the *KE* of a 70-kg-mass karateka's kick from a natural position (both legs are parallel to each other) at 9.9 m/s. The distance is not specified and the speed has been registered as an average speed. The kicking distance

usually is about 95 cm or a little bit more than 1 m. We did not take into consideration that the kick is executed against gravity.

The equation is $KE = 1/2\ m \cdot v^2 = 1/2(70\ \text{kg}) \times 9.9\ \text{m}^2 = 3430$ J.

8.6.2 Work

Work and energy link together and have a common usage. The daily work that people do requires energy. People moving objects, or simply walking, which requires energy, are examples of work too. A thinking process also means working. The work is a scalar quantity and is a product of magnitude of force needed to overcome a resistance and the displacement over which the force is applied (the object moved). Work $(W) = F \cdot s$ or $\text{N} \cdot \text{m}$, also expressed in joule, where s = displacement.

As mentioned earlier, energy and work have a common usage in mechanics and in general. Here is the so-called *work–energy relationship* that is related to physical work: This relationship states that the amount of work done is equal to the change in energy.

$W = \Delta KE + \Delta KE_{\text{ang}} + \Delta PE$, where ΔKE is the change in kinetic energy, ΔKE_{ang} is the change in angular energy, and ΔPE is the change in potential energy.

Work can also be described as the change of energy to another form of energy. This form of changing is also called *transduction*.

8.6.2.1 Concept of Work Related to Force

A person or an object can do *positive* or *negative work*. When the force acts in the same direction as the displacement, then the work done is positive. On the contrary, when the force acts in the opposite direction to the displacement, then the work done is negative. For example, when a weight lifter lifts a barbell overhead in one continuous movement, he exerts a *positive work* because the displacement of the force occurs in the same direction the object (weight) moved.

When the person lowers the barbell, his work will be *negative* because the force displacement occurs in the opposite direction. Recall that when isometric contraction occurs, there is no mechanical work (no force displacement). If the force is perpendicular to the displacement, for example, in the case of centripetal force, then no work has been done. When a force is applied to an immovable object, then the work is zero. The force of gravity does not work on a body that moves horizontally.

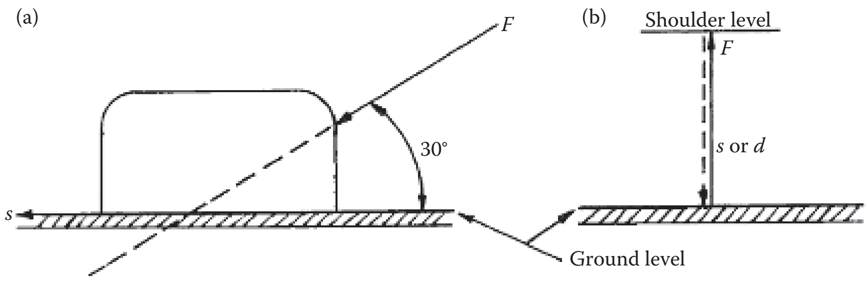


FIGURE 8.3 Demonstration of the (a) positive and (b) negative work.

In the following examples, it will be demonstrated and calculated that the work done = $F \cdot s$.

Example 8.1

Figure 8.3a shows a box full of supplies (it is pushed by somebody). The pushing is in the x axis with a force of 160 N. The force exerted is not in the same line with the moving object. This is at 30° angle with the x axis. The distance of pushing is 2.5 m.

Then, $W = F \cdot s \cos 30° = 160 \text{ N} \times 2.5 \text{ m} \times 0.866 = 346.4 \text{ J}$ (see Figure 8.3a).

Example 8.2

See Figure 8.3b. Recall Figure 6.2 from Chapter 6. Judoka B has been thrown with the technique of *Kata-guruma*. The force of lifting is (approximately) 850 N and the direction is at the vertical Y axis. The distance from the ground to the height of the starting execution (which is the shoulder level) is 1.6 m.

In this case, the direction of the force and the displacement are in the same direction (up) and will also be in the same direction (down) when the throwing technique will be executed. However, there will be less force put into the action, 686 N, which is the karateka's weight $(w) = m \cdot g$ (70 kg × 9.8 m/s^2). Here is the calculation of the work when the force is directed upward:

a. 850 N × 1.6 m = 1360 N · m work in positive direction.

Calculation of the work when the force is directed downward:

b. -1.6 m × 686 N = -1097.6 N · m work in negative direction.

Example 8.3

A man walking a distance of 10 m. His mass is 70 kg. This means that his walking force = mass × gravity = 686 N × 10 m = 6860 N · m (J). In the third case, the working effort (J) is much more because of the distance.

In Figure 8.3b, the intermittent line represents the returning action of throwing Judoka B as a negative work.

8.6.3 Power and Strength

The word *power* sometimes is confusing between athletes. Many times, people use the word *force* or *strength* instead of power. Power is the amount of work per unit time. Also, it is the product of force and velocity. Recall that the force has been described previously.

The term *strength* is the ability of a muscle or muscle group to exert force against a resistance. The strength is not a standard term in mechanics. It refers purely to muscle(s) by resisting forces within or against the human body. Here, we include concentric, eccentric, or isometric forces. The strength is usually measured as one maximal effort of one repetition maximum (1-RM).

Power (P) = $W/time$ or $P = F \cdot v$ or N · m/s. Power is measured in watts (W) = 1 N · m/s or 1 J/s. We can observe that force is present in both equations. Recall that $W = force \times displacement$. Calculating the work done by a force, the length of time is not taken into consideration.

Let us say a man of 70 kg (or 686 N) uses a pulley to lift up an object to a distance of 2 m. Thus, he could do about 1372 N · m or J work. Calculating the work for 2 m distance does not matter how fast he pulled up the object, for example, 1.5 or 2 s, the work is still 1372 J. In our case, the power rate is changed. For a better understanding, the power related to time is the following equation:

$$\begin{aligned}\text{Power} = \text{work/time} = \text{force} \times \text{distance/time} &= 70 \text{ kgf} \times 2 \text{ m}/1.5 \text{ s} \\ &= 93.33 \text{ W or J/s.}\end{aligned}$$

In mechanics, where engines provide the power for different vehicles (auto, airplane, ship, etc.), power is often measured in horse power (HP or

hp). The term "horsepower" is not used in SI unit (standard international unit of measurement); the unit watt (W) is used. However, the use of the term "HP" persists in many languages and industries. HP basically represents a unit of measurement of the maximum power output. HP presently is slowly replaced by kW and MW (megawatt).

As a curiosity about HP there are many terms with different standards that are presently used:

- Mechanical horsepower (hplb) = 33,000 ft-lb$_f$/min or = 550 ft-lb$_f$ or 745.6999 W
- Metric horsepower hp(M) or mHP = 75 kg-f m/s or 735.49875 W
- Electrical horsepower hp(E) = 746 W
- Boiler horsepower
- Hydraulic horsepower and so on

8.7 MUSCLE POWER

Recall that the amount of power delivered by a person depends on two components: force and velocity. In other words, if you have force which you do and you have velocity more or less, then you could have power output. In this way, when an instructor asks to you to put more power in your hit, he means to put more force or speed in your action. By using one word "power" the instructor accomplished exactly the usage of the two most important physical qualities in martial arts: force and velocity (speed).

Physical educators should know that at zero velocity or at the highest velocity, no power is produced ($P = 0$ or $F = 0$). The maximum power output should occur at about the 1/3 maximum speed. The muscle can develop the highest force when it is being stretched (negative velocity).

The human muscle strength generates the force needed to do the mechanical work, which is the mechanical power (N-m/s). The muscle fiber (cell) is the generating system. Inside the muscle cell, there are many important organelles, but two of them are the most important for generating force.

One of them is *sarcomere*, which is the basic functional unit of the muscle cell, composed mainly of the contractile proteins, *actin* and *myosin*. The other, which can be found in any cell, is *mitochondria*. These organelles are the cells' "powerhouse," generating ATP, the universal form of energy used by all cells. This energy is produced by oxidation of food.

The power produced by a muscle is dependent on its mass and its density. Different dates from the scientific literature state that the maximum power that 0.45 kg (1 lb) of muscle can extract is approximately 1/8 HP metric, which is 735 W.

From here, the maximum force can be 30–100 N/cm^2.

Maximum speed is 2–5 lengths of muscle/second.

Muscle density is approximately the same as water: 1000 kg/m^3.

Also, sarcomere length strongly influences muscle strength generation. Long sarcomeres can achieve more cross bridges, and therefore can produce a large amount of force. They contract slowly. Short sarcomeres have a greater velocity but the force production is less.

Strength also depends on the cross-sectional area (CSA) of a muscle. The distance of the application of force also depends on the total length (L) of all muscle fibers of a single muscle bundle. The power generated depends on the speed of the muscle movement. A high speed means a short time for the movement to produce high power. Figures 8.4a, 8.4b, 8.5a, and 8.5b explain different interactions between isometric and isotonic muscle

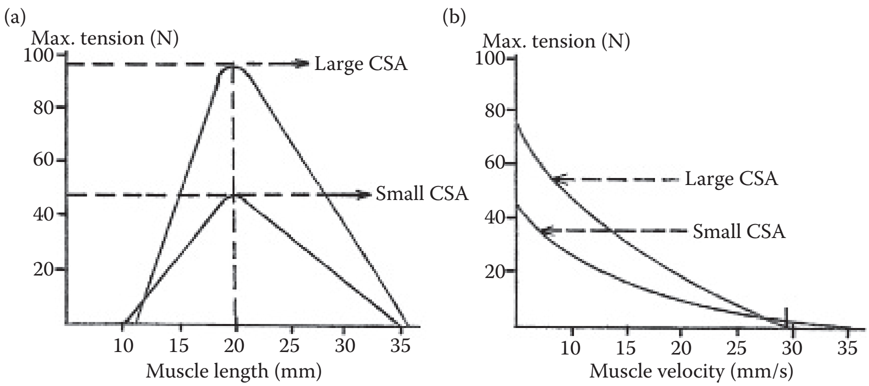


FIGURE 8.4 (a) Muscle length and muscle tension relation under isometric contraction. The muscle with large CSA can reach a higher maximal tension about 97–100 N. N denotes Newton. (b) Force velocity relations under isotonic action. Both have identical mass. Muscle lengths are the same; however, the force output is less for a small CSA. The effect of increased CSA with identical fiber length and identical mass is to shift the absolute length–tension and force–velocity curves to higher values but with the retention of the same range and intrinsic shape. (Adapted from Lieber R.L., Friden J. 2000. *Muscle & Nerve*, 23, 11.)

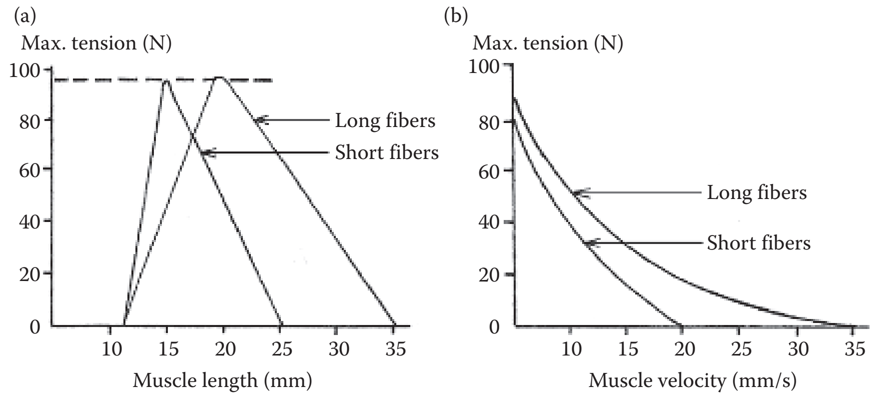


FIGURE 8.5 (a) Comparison of isometric length–tension properties. (b) Comparison of isotonic force–velocity properties. The effect of increased fiber length is to increase the absolute range of the length–tension curve and absolute velocity of the force–velocity curve but with retention of the same peak force and intrinsic shape. The muscle with longer fibers generates a greater force. (Adapted from Lieber R.L., Friden J. 2000. *Muscle & Nerve*, 23, 11.)

tensions related and compared to different factors such as muscle length, velocity, and CSA of the muscle.

Both figures represent two muscles with different fiber lengths but identical CSAs.

Power output also depends on the different types of training, such as isometric, dynamic, and isokinetic. During an isometric type of training, there is no power output and the isometric action develops only strength. During isometric exercise, the potential energy is transferred into heat energy. During an isometric contraction, the muscle tension is equal to an external force and the muscle stays at the same length. This is also called *static equilibrium*. We cannot measure any mechanical energy or mechanical work and furthermore there is no force to be measured.

Determining the power output must be done under the dynamic (isotonic) training. During an isotonic contraction, the muscle tension is greater than an external force, and the muscle contracts. Using isokinetic training for calculating the power output is somehow easier because the speed is constant and as we know, only the force input can be changed.

Let us continue to discuss the *force, power, strength,* and *velocity* relationships.

The velocity of muscle contraction is inversely proportional to the load. The force and velocity relationship also states that velocity and force are

inversely related to concentric movements. A great force cannot be exerted in a very rapid movement (example is the "dead lift" in weight lifting). The maximal velocity can be obtained by using less loading.

The author's opinion, however, is that the maximal velocity can still be obtained even using the maximal load, but for the infinitesimally short time (Olympic weight lifting "snatch"). In this case, we speak about *impulse* = $F\Delta t$. However, there is no contact to be considered as a real impulse.

Recall the golfer using his club to deliver the force to the ball, by using a long time for the effectiveness of the force required for gaining distance. By the same token, the karateka uses an extremely short time to achieve maximal force. In general, it can be stated that a maximal power output can be obtained: $P = F \cdot v =$

1. Maximal force × low speed
2. Minimal force × high speed
3. Medium force × medium speed

So far we described the power in view of physics; however, power is present at the mental and/or physiological level, but here the power is represented by the physical property of the energy where the kinetic energy spent is divided by the change in time. $(P) = \Delta KE/\Delta t$.

As we already know that kinetic energy changes from one form to another form or is transferred, and power is a measure of how fast those energy changes are happening. Humans generate power every day with different activities by spending energy.

Let us give some examples about energy spending related to power. On Earth, it takes about 10 N · m of energy to raise a 1 kg mass to a height of 1 m. We know that 1 N · m = 1 J, so that is 10 J in our example. If a person lifts a 2 kg weight to 1 meter in 1 s, then the rate of energy conversion is 2 × 10 = 20 J/s or 20 W of power.

Let us take another example: you move a 1 kg weight more slowly so that it takes 2 s to lift it to 1 m. Now the rate of work is 10 J (N · m) of energy every 2 s. Remember that 1 W = 1 J/s energy conversion. J/2 s = 5 J/s = 5 W. 1 kcal = 4813 J or 4.184 kJ = 4.184 kW. The kcal is the thermal representation of the energy. The kilojoule is the mechanical representation of the energy.

Recall that humans generate power by doing things in their life. In order to estimate your caloric expenditure, you should know about your

basal metabolic rate (BMR) or resting metabolic rate (RMR). The BMR represents the minimal rate of metabolism in an individual at complete rest, at normal body temperature when one is not consuming food. There are many different formulas; however, here is a most used formula. The BMR is expressed as hourly values of heat production per meter squared per hour rate.

The BMR is directly related to your fat-free mass and is generally reported in (kcal)(kg)(min) rate. If we take into consideration an average man of 70 kg, age 55, he can have a BMR approximately of an average rate between 0.9 and 1.5 kcal/min. He can also consume 1.5–2.5 mL oxygen/min.

If a man sits/watches TV, he can spend 1.20 kcal energy per min energy; when walking he spends 2.05 kcal/min, and when jogging he spends 8.10 kcal/min. Let us take the first proposition only—sitting: 1.2 kcal × 60 min = 72 kcal/h or kW/h, which in our case represents the use of power.

8.8 STUDY QUESTIONS

1. A karateka kicks a stationary punching bag with a front kick. Estimate the contact force given by the foot that has a mass of 1.28 kg. The karateka has a mass of 70 kg. The kicking foot accelerates from 0 to 12.5 m/s in 0.02 s. The kick has a constant acceleration. What is the acceleration of the foot and what is the force of impact?

2. Does an object with mass (*m*) that moves with constant speed have momentum?

3. Does the momentum always change or not during impact?

4. Can an object with less mass have the same momentum of an object with more mass?

5. Describe the difference between momentum and mechanical energy.

6. If an object does not have momentum, can it have mechanical energy?

7. When does impulse occur?

8. Explain what changes can occur during an impact.

9. When an elastic object is moving and collides with an inelastic object, which object undergoes damage (if any): the elastic or the inelastic object?

10. Can the kinetic energy be conserved in an elastic or inelastic collision? Explain in your own words.
11. Calculate the *PE* of Judoka A who is on the back of Judoka B. Judoka A will be thrown from the shoulder to a distance of 1.50 m. The Judoka A has a mass of 80 kg.
12. What is the *KE* of a 0.25 kg arrow that travels at a velocity of 18 m/s?
13. Determine the work done if you lift a man of 70 kg to a height of 1.20 m.
14. Calculate the power when you lift an 80 kg body mass to a height of 1.20 m in 2 s.
15. What causes the *KE* to be more effective than momentum?
16. What are those physical properties that can influence *PE*?

CHAPTER 9

Kinetics in Angular Motion

Recall that martial arts involve almost totally 3-D actions. This chapter describes almost all those physical properties and physical quantities that were described in the previous chapter. Every description of course will be related to angular motion.

9.1 FORCES

In angular motion, there are many different forces, such as eccentric, concentric, centripetal (radial), tangential, friction force, and others, which can act on a body or a point of mass differently. To these forces the speed/velocity and acceleration are directly related to the object in cause. These forces act of course through different distances. Distance, displacement, speed, velocity, and acceleration have been described at the angular kinematics. We will describe mostly the action of the forces.

When we speak about eccentric or concentric forces, we should not be confused with the external and internal forces. These two forces has nothing or little commune with any motion to be translational or rotational. These two forces have been described earlier.

9.1.1 Couple and Eccentric Force

We know that for any movement to occur, a force must be present. In rotary action also, a force must be present. Basically, any rotation of a mass/body first involves a translatory movement, and then will turn into

a rotary movement. This translatory motion has seemingly an extremely short time. Here is an example of how in fact a rotary motion happens.

Two wrestlers A and B face each other. If wrestler A pushes wrestler B exactly on the middle of the chest, then B will presumably have a direct backward linear motion. If the same wrestler A pushes B again but at the shoulder, then a body rotation will occur in the direction of the pushing force. Most of the time when the force of pushing acts through the CoG or CoM, then a translatory motion will occur. This kind of pushing force almost never happens in martial arts. There is always a possibility that the force will not go through the CoG.

A force whose line of action does not pass through the CoG of the body on which it acts (or through the point at which a body is fixed) is called an *eccentric force*. This force produces translation and rotation. Its rotatory effect is known as *torque*. On the contrary, a force that has its line of action passing through the CoG of the body on which it acts is called *concentric* or *direct force*.

Let us again use our example of the pushing force by a wrestler. If wrestler A pushes with his right arm the left shoulder of wrestler B, who in turn pushes back with his right arm wrestler A at his left shoulder, there will be a rotatory force exerted by both wrestlers. The forces are eccentric and presumably equal in magnitude.

Both wrestlers' forces have the tendency to go linear; however, they will be cancelled because of the equal magnitude of both forces. The remaining tendency of each force to rotate the opponent body in a counterclockwise direction will turn the linear force to rotational force. These equal and opposite parallel forces is called a *force couple* or just *couple*. There are many examples in daily life, e.g., pushing the bicycle pedals or turning your car driving wheel.

In martial arts, a force couple happens very seldomly. As we know that in martial arts the majority of techniques executed most of the time involve two persons and they must have contact to each other in order to have a couple.

Recall that every rotational movement involves first a linear movement and at the time when we could speak about a force couple, the physical properties involved are strength, speed, and acceleration. To say it better, a momentum ($p = m \cdot v$) is involved. So, in this case, there is never a real force couple involved because the momentum of a person differs from the momentum of the other person. The explanation about momentum will be described later on.

9.1.2 Centripetal and Centrifugal Forces

During a back-fist strike (*Uraken-uchi*) executed by a karateka, muscles such as pectoralis major, deltoid, teres major, latissimus dorsi, and subscapularis exert forces on the arm of the karateka. The resultant of these forces can be resolved into two components: The first one acts along the line of the arm through the shoulder joint, which should be considered as the axis of rotation and is named as the radial component of the force (F_{rad}).

The second component that acts perpendicular to the radial force component is named the tangential force (F_{tan}) (Figure 9.1). This tangential force is responsible for the angular acceleration that increases the tangential velocity of the striking arm. The *radial force* acts toward the center (axis of rotation) and this force is referred to as the *centripetal force* or center-seeking force.

The radial acceleration involves change of direction continuing perpendicular to the direction of motion. Here are the equations for radial acceleration and radial (centripetal) force. Radial acceleration $a_{rad} = v^2/r = \omega^2 r$ and radial force $F_{rad} = m \cdot v^2/r = m \cdot r \cdot \omega^2$. Here, v is the magnitude of the tangential circular velocity or speed and r is the length of the radius of rotation.

Let us take an example and calculate the radial force. A karateka strikes toward the opponent's face with a technique back-fist strike *(Uraken-uchi)* as shown in Figure 9.1. The karateka weighs 70 kg, which we do not count at this time; his total arm mass is 3.45 kg; the velocity is 11 m/s; and the total arm length (with the fist closed) is 0.69 m. $F_{rad} = m \cdot v^2/r = 3.45\ \text{kg} \times 11^2/0.69\ \text{m} = 605\ \text{N}$.

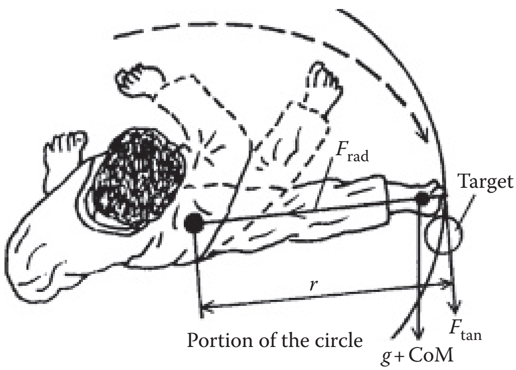


FIGURE 9.1 Radial and tangential forces.

Centripetal force coexists with another force named *centrifugal force*. The word comes from the Latin word "centrum" (center) and "fugere" to (flee). The centrifugal force has two slightly different manifestation forms:

- *Reactive centrifugal force* that occurs in reaction to a centripetal acceleration on a mass. This force is equal in magnitude to the centripetal force and is directed from the center of rotation. We can observe this force when we are sitting in a car. When the car is turning to the left, our body moves to the right. This motion to the right is the centrifugal force. In martial arts, an example of the centrifugal force manifestation is the aikido technique named "entering throw—negative" execution *(Irimi-nage)*. Here, the executor (attacker) *(Shite)* guides the opponent in a rotary fashion. The defender *(Uke)* feels that the guiding force throws him away from the closeness of his attacker. Besides the attacker's guiding force, the defender also feels the centrifugal force. More description about the centripetal and centrifugal forces can be found under Part IV.
- *Pseudocentrifugal force* appears when a rotating reference frame is used for analysis. The true frame acceleration is substituted by a pseudocentrifugal force that is exerted on all objects, and directed away from the axis of rotation.

Figure 9.1 is seen from the top of the head of the karateka. As you can see the tangential force is perpendicular to the radial force. The drawing shows that the technique starts with the elbow bent.

However, for the correct calculation of the angular velocity and the radial force, the arm should be completely extended. r represents the radius of the circle and also the total length of the arm.

9.2 CENTER OF MASS

As we know already that every object/matter is comprised of mass. This amount of mass has a volume and density. The amount of mass also has its center, what we call the center of mass (CoM). This CoM represents the average position of the mass distribution of an object and it is considered that the mass of the body lies within the CoG.

The linear and/or rotational movements and their positions of the rigid bodies can be analyzed by finding out the CoG positions of the body in case. There are different methods to find out the CoG of a rigid body. One

method is the *reaction board method*. We will not describe these methods in this book. The entire mass of a rigid body may be assumed to be at the CoM of the object in case considering that the object is under an action of an external force.

Generally, the CoM of a body coincides with the CoG of that body. The CoM and CoG are located just under the navel at an approximate distance of 4 cm. The CoM and also the CoG have a location not only within the body, but can also be found outside of the moving body.

Analyzing the CoM of a rigid body is much easier than analyzing a non rigid body. Analyzing a rigid body, the researcher uses different geometrical shapes, which is similar to the body that will be analyzed later on. Let us consider two examples: A ball that rolls down a path and has an inclination of θ, or a ping-pong racket thrown up and forward in the air will certainly have a different path and also a different CoM.

In the first example, the forces appear to operate on a straight line and the CoM = $m \cdot g \sin \theta$. In this example, the CoM appears to be exactly in the middle of the ball. In the second example of throwing a ping-pong racket, the path will be a parabolic one. Here the CoM = $m \cdot g$ only. It is possible to be stated that the CoM is a geometric point, which holds together all the mass and external force(s) during motion. To calculate the CoM of a system of particles, we use the following equation.

$$\text{CoM}_{\text{position}} = \frac{\Sigma \text{ mass of individual particle} \times \text{position of particle}}{M_{\text{total}}}$$

Substituting with appropriate symbols, the equation will become $\mathbf{r}_{\text{CoM}} = \Sigma\, m_i\, r_i / M_{\text{total}}$, where r_i is the position of individual particle, m_i is the mass of individual particle, and $\mathbf{r}_{\text{CoM}}$ is the position of CoM. See Appendix C where two karateka CoM is described with figures and equations.

The above equations are useful for the CoM of individual particles that are rotating in the same path. However, if the mass of the individual particle(s) is rotating by moving in different paths or this moving from one path to another will take time, then the original equation will be different, and vector components must be used for the above calculations. Let us presuppose that two objects are located on the same axis (X) and both objects are moving from left to right and the pivot point also moves to the right, then the equation for the particle masses will be $\Delta x_{\text{CoM}} = m_1 \Delta x_1 + m_2 \Delta x_2 / m_1 + m_2$, where x_{CoM} is the pivot point, m are the point masses, and x is the

moving distance of the point masses. If we also take into consideration the time spent (velocity) by moving the point masses, then the equation would be $V_{\text{CoM}} = m_1 \cdot v_1 + m_2 \cdot v_2/m_1 + m_2$, where v is the velocity; however, this equation is not realistic because calculating the CoM should not involve time spending, rather it should involve the distance all the time.

9.3 EQUILIBRIUM

Equilibrium is strongly related to the CoM. When the body loses its equilibrium, the CoM is out of its initial place. When an object is in equilibrium, its state of position or motion is not changing. An obvious condition for equilibrium is that the net force acting on the object must be zero. From Newton's second law, $F_{\text{net}} = m \cdot a$, then we have that the acceleration = 0 and the velocity is constant. This requirement for a point mass to be in equilibrium is not a guarantee of a rigid body to be in equilibrium.

There are several basic conditions for equilibrium:

- $F_{\text{net}} = 0$, which mean that for a 3-D movement of x, y, and z, components of forces may be separately set = 0.
- $F = 0$, which mean that forces left = forces right and forces up = forces down.
- During a perfect rotary equilibrium where the rotational condition is not changed, the net torque must be zero. This condition is a requirement that the sum of all clockwise (CW) torques must be equal to the sum of all counterclockwise (CCW) torques. For a rigid body to be in a complete state of equilibrium, it must first be in a state of *translational equilibrium* where the sum of all the forces equal zero.

The conditions for a body to be in equilibrium under angular motion have been stated earlier. Now, how can we calculate equilibrium? The majority of motions involve torque. But torque involves moment of inertia, lever(s), and angular acceleration. The torque is apparent when the body has contact with a force and also has contact with the center of the rotation that is connected to the line of action where the force is activated. In this case, we speak about torque, which we will describe later.

But what about a body that has no torque, for example, a man running with a constant speed in a circle, which, let us say, has a diameter of 20 m. In this case, how do we know that he lost equilibrium? Just by watching

the man and eventually seeing him tumbling several meters, we realize that he is losing balance.

How can we calculate those short meters when he lost the balance? In this case, even if the force is present, because there is a (presumed) constant acceleration, we should use the linear kinematic calculations. You may be asking why we do not use the rotational kinematic calculations.

In our case, a man who represents a point mass is extremely minuscule in relation to that circle of 20 m diameter and basically he is running in a straight line where the curves have a very large radius from a point that we can consider to be a fulcrum. That is why we use the following equations that are shown under the following section. When the athlete runs around the circle, we have the following forces.

There is centripetal force acting from the athlete toward the imaginary center of the circular path. Now, for the athlete to rebalance his position, the frictional force should act away from the center of the circular path. The normal force of the athlete acts vertically upward and has a magnitude that is equal to his weight. Then, the normal force $N = m \cdot g$. The *frictional force* (f) acting on the athlete is $\mu \cdot m \cdot g$. The centripetal (radial) force $F_{rad} = m \cdot r \cdot \omega^2$ or $m \cdot v^2/r$.

For the athlete to be in equilibrium, the net force acting on the athlete must be equal to zero. We take a negative (–) sign in the direction toward the center. Then, $-F_{rad} + f = 0$. Continuing our calculations, we obtain $m \cdot r \cdot \omega^2 = m \cdot g$ or ($m \cdot v^2/r = mg$).

9.4 TORQUE AND LEVER

When a working man applies a force by using a wrench to turn, for example, a bolt, that turning force is called *torque* or *moment*. Recall that the linear acceleration is caused by force. By the same token, the angular acceleration is caused by torque. The turning effect of an eccentric force is called torque. A specification is required about the terms *torque* and *moment*. Both terms indicate a turning force effect.

The term *moment* as stated earlier is used more by biomechanists as a bending or rotation action by the muscle force. The term *torque* is used more in physics and mechanics representing a twisting force. By the way, both words are interchangeable. The force of torque is a vector that has magnitude and direction. The torque rotation can be either in a positive direction that is CCW or negative that is CW. A (+) or (–) sign must be accounted when calculating the net torque.

When more than one force acts on the moment arm, then we have to add all the forces that will result in a net force. As described earlier, when a force couple is acting on a moment arm and they are equal in magnitude and they can overcome the resistance of the object, translational motion will occur.

In the human body, there are many examples of force couple and those help to turn the body part to the required direction. For example, a force couple is the upper part of the trapezius muscle, which elevates and rotates the scapula upward and its counterparts are two muscles rhomboids minor and major that rotate the scapula downward. Two other muscles having the role of force couple are biceps brachii and triceps brachii.

The terminology of the torque represents a magnitude of the force (F) "applied" and that is multiplied by the perpendicular distance (d) from the axis of rotation to the line of force action. This perpendicular distance is named *moment arm*, *resistance arm*, *force arm*, or simply *lever arm*.

The distance can also be considered between the CoM and the force point of application. Therefore, the equation of the torque is $(T) = F \cdot r$ or $\mathrm{N} \cdot \mathrm{m}$ (Newton meter). If the moment is preferred instead of torque, then moment $(M) = F \cdot d$. Scientists use the r, d, l, or even x interchangeably. They all represent the distance. To be more correct, $r(\vec{r})$ is the displacement vector and d is the shortest distance from the axis to the line of action of force (F), which usually represents the moment arm. The torque is also represented by $\Sigma T = I \cdot \alpha$, where I is the moment of inertia and α is the angular acceleration.

These units are good mostly when the moment arm is perfectly perpendicular to the line of force action from the axis of rotation (Figure 9.2a). If

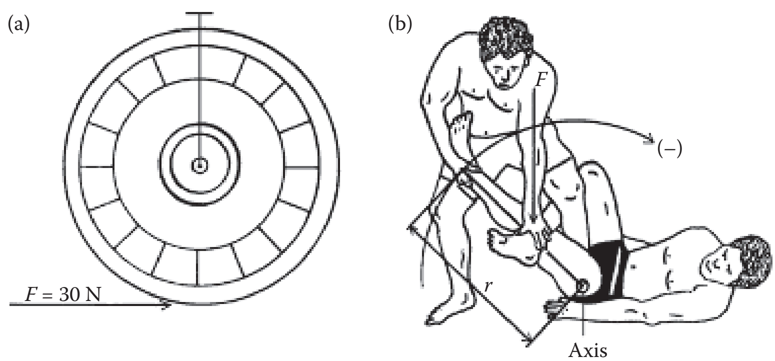


FIGURE 9.2

the moment arm is not perpendicular to the line of force action, then the equation is the following: $T = F \cdot d$ (sin θ) (Figure 9.2b).

Figure 9.2a shows a *simple lever* meaning that there is only one arm that acts as the force arm. To increase the efficiency of torque using a simple lever, the lever arm should be longer to increase the force that acts at the end of the lever. Take any kind of wheel and rotate. The wheel is hung by its axis. The diameter is 0.75 m and the force applied tangentially to the wheel is 30 N. Find out the torque. The radius (r) will be 0.375 m.

Figure 9.2b shows a different situation of torque. Here, the moment arm is not perpendicular to the force of application. In this instance, the moment arm acts at θ related to the force of line. Two martial artists (Jujutsuka) are in a clenched position on the ground. On the top, A applies a force of 80 N. The pivot point is at the coxofemoral articulation of the Jujutsuka (B). The moment arm is from the coxofemoral joint to the ankle of the same leg.

The force applied by A is the left arm and is at the angle of $\theta = 45°$ to the moment arm. The distance [radius (r)] = 0.85 m. The right arm and the right thigh of A basically control the left leg of B by pressing B's left ankle against A's right thigh. We neglect here any forces. The semicircle shows the direction of the presumed rotation, which is oriented along the x abscissa and vertically to the y ordinate line. Find out the torque.

Calculate the torque for Figure 9.2a. $T = F \cdot r = (30\text{ N})\ (0.375r) = 11.25$ N · m. The diameter 0.75 is divided in order to receive the radius or lever arm, which gave us 0.375. Calculate the torque for Figure 9.2b. $T = F \cdot r$ (cos 45°) = (80 N) (0.85 m) (0.707) = 48.08 N · m.

9.5 MOMENT OF INERTIA

Rotational inertia or *moment of inertia* (I) is a measure of how difficult it is to change the rotational velocity of an object that is rotating about an axis. The moment of inertia depends on the total mass of the object as well as the distribution of the object mass about the axis of rotation. Further, the mass from the axis is greater than the moment of inertia, so the moment of inertia is directly proportional to the object's mass.

The heavier an object the more force it takes to move the object and also more force needed to stop that moving object. Also, if the point mass of the moment of inertia is closer to the axis of rotation, the velocity is higher than in case if the point mass is located further from the axis of rotation.

Rotational inertia acts in the same manner as the linear inertia. The major difference between the linear and rotational inertia is that the

starting and/or stopping the object is more difficult in rotational motion than in linear motion. In daily life as well as in sports, there are countless examples of the moment of inertia: baseball bat striking, hammer throwing, rolling a bowling ball, a gymnast executing a somersault or in martial arts a roundhouse kick, and a fencing saber cut, to mention just few. All these examples with their technical characteristics must be related to the object mass, rotary motion, and the distance of the mass from the axis (rotating) point.

The moment of inertia equation shows these physical characteristic relationship. From here, $I = \Sigma\, m \cdot r^2$ ($\text{kg} \cdot \text{m}^2$). The Greek capital letter sigma (Σ) represents the sum of the total mass, m is the mass or point mass, and r^2 represent the distance squared between the axis of rotation and the mass particle.

To calculate the moment of inertia of a point mass that rotates parallel to the ground at a certain distance r from a fixed axis point is easy; just use the above-described equation. If there are more point objects that are rotating about the same axis, but at different distances from the axis, then the total moment of inertia of the system is equal to the sum of the individual moments of inertia, $I = \Sigma m_i \cdot r_i^2$. In this case, if there are many masses and many distances, each of them having their particular moment of inertia, then the moment of inertia can be calculated in the following way: $I_2 = m_2 \cdot r_2^2 + I_3 = m_3 \cdot r_3^2$, then $I = I_1 + I_2 + I_3 \cdots$.

In calculating the moment of inertia of an object, for example, baseball bat that is swung by an athlete, besides knowing the actual weight of the bat, the *swing weight* of the bat should be considered too.

9.6 PARALLEL AXIS THEOREM

Parallel axis theorem states the relationship between the moment of inertia about an axis through a segment's CoM and about any other parallel axis. $I_a = I_{\text{CoM}} + M \cdot h^2$, where I_a is the moment of inertia about an axis other than through the joint center, I_{CoM} is the moment of inertia of the body about the parallel axis through its CoM, M is mass of the segment, and h is distance from the joint center to the segment center of mass (distance between the parallel axes). The $M \cdot h^2$ can be substituted with the $m \cdot r^2$ or $m \cdot d^2$, where m is the mass and r or d represents the distance.

Books of biomechanics often describe body weights and its segments and you can also find moments of inertia of body segments about transverse axes through their CoG or CoM.

TABLE 9.1 Weights of Body Segments Relative to Total Body Weight of 70 kg

One Body Segment	Relative Weight (kg)
Head	5.11
Trunk	35.49
Upper arm	1.82
Forearm	1.12
Hand	0.49
Thigh	7.21
Calf	3.01
Foot	1.05

Source: Adapted from Hay J.G. 1993. *The Biomechanics of Sports Techniques* (4th ed.). Prentice Hall, Inc.

TABLE 9.2 Moments of Inertia of Different Body Parts about Transverse Axes through Their CoM[a]

One Body Segment	Moment of Inertia ($kg \cdot m^2$)
Head	0.0250
Trunk	1.2600
Upper arm	0.0210
Forearm	0.0070
Hand	0.0007
Thigh	0.1050
Calf	0.0500
Foot	0.0035

Source: Adapted from Hay J.G. 1993. *The Biomechanics of Sports Techniques* (4th ed.). Prentice Hall, Inc.

[a] Body weight of 70 kg.

Tables 9.1 and 9.2 describe these body weights by segments and their moments of inertia. To correctly calculate the CoG of different segments of an athlete, see Figure 9.3.

Figure 9.4 gives an example of calculation of different segments' moment of inertia by using the parallel axis theorem of a karateka who just recovered his leg after a kick or who is ready to kick. Using the parallel axis theorem, the moment of inertia of the thigh about the hip axis is

$$I^{I}_{\text{hip}} = I_{\text{CoM}} + M \cdot h^2 = (0.1052) + (7.21)\,(0.28)^2 = 0.6704\ \text{kg} \cdot \text{m}^2$$

Similar calculations yield the moment of inertia of the calf about the hip axis:

$$I^{II}_{\text{hip}} = I_{\text{CoM}} + M \cdot h^2 = (0.0504) + (3.01)\,(0.40)^2 = 0.532\ \text{kg} \cdot \text{m}^2$$

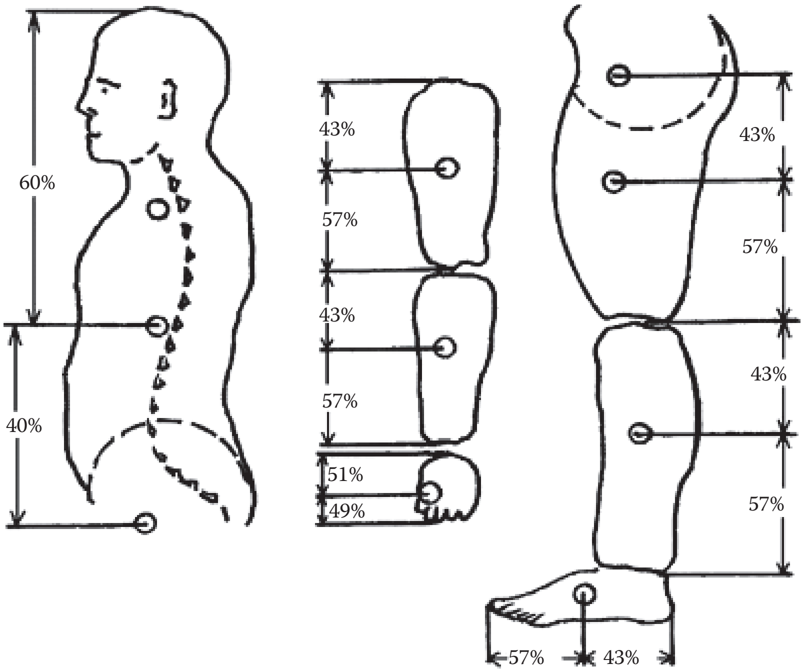


FIGURE 9.3 (Adapted from Dempster W.T. 1955. Space Requirements of the Seated Operator, USAF, WADC, Tech. Rep. Wright-Patterson Air Force Base, Ohio.)

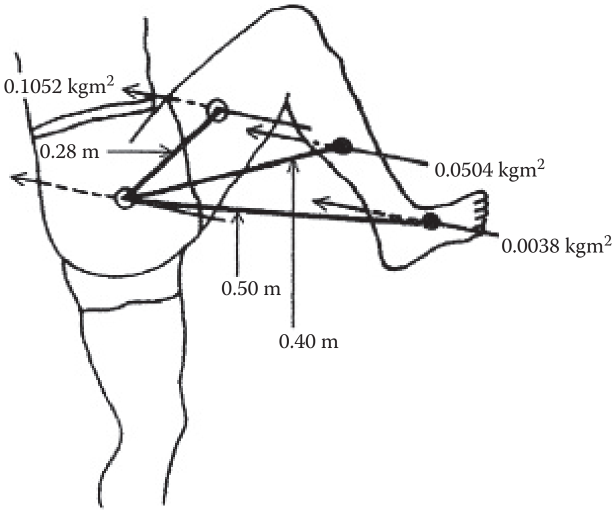


FIGURE 9.4

The moment of inertia of the foot about the hip axis:

$$I^{III}{}_{\text{hip}} = I_{\text{CoM}} + M \cdot h^2 = (0.0038) + (1.05)\ (0.50)^2 = 0.2663\ \text{kg} \cdot \text{m}^2$$

To calculate the moment of inertia of the whole lower limb about the hip axis, we must add the final results of the three segments:

$$I_{\text{hip}} = I^{I}{}_{\text{hip}} + I^{II}{}_{\text{hip}} + I^{III}{}_{\text{hip}} = (0.6704 + 0.532 + 0.2663)\ \text{kg} \cdot \text{m}^2 = 1.4687\ \text{kg} \cdot \text{m}^2$$

The parallel axis theorem obviously can be used to all body segments. To find out the moments of inertia for different body segments, scientists compare symmetrical bodies usually using the central axis (CoG or CoM) of the body in case.

The reader should consult different scientific publications about these symmetrical bodies' moments of inertia, such as hoop, cylinder or ring, disk, solid cylinder, thin or thick rod, solid sphere, slab, spherical shell, and so on. The axes of these symmetrical objects are established through transversal, sagittal, or longitudinal axes of the body in case. Here are some examples of the moments of inertias of some symmetrical and/or uniform rigid objects:

1. Thin hoop where the axis of rotation is centered. $I = m \cdot r^2$
2. Thin rod of uniform mass density with m = mass, l = length of rod, axis at the center of the rod. $I = 1/2\ m \cdot l^2$
3. Thin rod of uniform mass density, the axis at the end of the rod. $I = 1/3\ m \cdot l^2$
4. Thin rectangular slab with lengths a and b. The axis through center. $I = (1/12)\ m(a^2 + b^2)$
5. Thin walled hollow sphere with axis through center. $I = 2/3\ m \cdot r^2$
6. Solid cylinder with axis through center. $I = 1/2\ m \cdot r^2$
7. Solid cylinder with three axes (x, y, z). $I = 1/12\ m(3r^2 + l^2)$
8. Thin-walled hollow cylinder with axis through center. $I = m \cdot r^2$
9. Thin rectangular plate with length = l, width = w and axis of rotation is centered. $I = 1/12\ m(l^2 + w^2)$
10. Thin rectangular plate with length = l and width = w and the axis of rotation is on the length side of the object. $I = 1/3\ m \cdot w^2$

11. Circular cone with the axis through the centers of x, y, and z axes and meets the thin edge point of the cone. The cone longitudinal axis is through the x line/axis. $I = 3/10\ m \cdot r^2$

12. Solid sphere about any diameter = $2r$. $I = 2/5\ m \cdot r^2$.

Figure 9.4 demonstrates the parallel axis theorem. Looking at Figure 9.4, the black round spots represent CoM or CoG. Two other small circles (they are not black) also represent the moment of inertia of body parts about transverse axes through their CoM. The 0.28, 0.40, and 0.50 m represent the distances between the CoM of different body segments.

Figure 9.3 shows in percentage the location of the mass centers of body segments.

9.7 ANGULAR MOMENTUM

Recall that linear momentum is a vector quantity that has a magnitude and direction. A body or an object that has a motion has a momentum that measures the velocity and the quantity of that mass or body. To put into simpler words, the momentum is a measure of the force needed to start or stop a motion. Therefore, linear momentum (p) = $m \cdot v$ (N · s) or kg · m/s.

In a similar way, the angular or rotary momentum H or (L) = moment of inertia times angular velocity. $L = I \cdot \omega$ or kg · m²/s. The momentum of a diver who dives in a straight line is the equation $p = m \cdot v$; when the diver starts to rotate he has the equation $L = I \cdot \omega$.

In contact sports such as karate, boxing, and so on, the linear momentum is closely related to the linear impulse (see Section 8.5); in the similar way in rotary motion, the rotary impulse (which will be described later) is also related to angular momentum. When a body rotates normally, it will not stop until a force intervenes in its rotation route?

Let us take an example of a discus thrown. The discus will spin in the direction liberated by the thrower. The discus will rotate around its center (CoG) and also advances forward. The angular momentum $L = I \cdot \omega$ (kg · m²/s). For any rotating object or body that is free from net torques, such as throwing a discus where the body rotates about a central axis, we can write the angular momentum $L = I_o\omega_o$ = constant, where I_o and ω_o are the moment of inertia and the angular velocity representing the initial time of "0" and the final time, which is also "0." Because the moment of inertia and the angular velocity cannot be altered, we can say the angular velocity (ϖ) is constant.

So what stops the angular momentum? The discus slows and will eventually stop by the gravity and the force of *drag*.

In order to alter an object's angular momentum and its rotational motion, the object's or body's shape must be changed in order to increase or decrease the speed of rotation. An example is the skater who is spinning on the ice about his vertical axis. The skater to increase the speed of rotation pulls his arms close to his body, by this movement he increases the velocity and decreases the moment of inertia. By his arms movement, the angular momentum is still constant because there are no external forces to change the angular momentum.

When we take another example, the discus thrower, he will not pull his arms to his body, he will keep them as far as possible; by this action, his moment of inertia will be large and above all he increases the distance of throwing by using his *linear impulse.* Angular impulse involves torque and time. Since the disc has no torque acting on it means that there is no angular impulse. The angular impulse is the change in angular momentum (ΔL), but the rate of change of ΔL is the torque, then $T = \Delta L/\Delta t = \text{kg} \cdot \text{m}^2/\text{s}$.

When a flying object starts to move having a certain amount of momentum and later on the object encounters some external force(s), the body will experience the expected impulse. Recall that the impulse can be increased by adding more force to the impact or by increasing the time delivery before the impact.

Reading about momentum here, the reader can see that there are several important physical properties that almost all the time are related to linear or angular momentum. These properties are moment of inertia, impulse, velocity, time, energy, and mass. Let us take a look at these physical properties' relationship to angular momentum.

9.8 ANGULAR MOMENTUM, MOMENT OF INERTIA, IMPULSE, ENERGY, AND POWER RELATIONSHIP

Angular momentum is directly involved with the physical property of impulse. The *relationship* of *impulse–momentum* is derived from Newton's second law, which states that the impulse of a force is equal to the change in momentum that it produces.

In other words, the impulse of a force acting for a given time interval is equal to the change in momentum assuming that the mass remains constant while the velocity changes from v_i to v_f, where v_i is the initial velocity and v_f is the final velocity. So far the essence of each physical property

has been described, but a question remains for martial artists and/or any other athlete: how to co-relate these physical properties when is used most effectively in the technical execution of the athlete.

Let us analyze a few martial arts. First of all we must know that these physical properties depend on the athlete's body size (height and mass of the body) or simply named somatotype. The athlete's general physical ability and the knowledge of the use of his body mechanics (techniques) also have to taken into consideration. The following examples will mostly describe angular motion techniques.

Let us take an example from karate and analyze the roundhouse kick *(Mawashi-geri)*. The kicking motion starts when the kicking leg (let us say the right leg) thigh is picked up and held at the horizontal level sideways at frontal plane; the calf must also be held (stuck) to the thigh. The axis of rotation is the coxofemoral articulation. At this position, the moment of inertia would be small if the rotation of the thigh starts. Recall that the angular momentum (L) = $I \cdot \omega$.

The inertia being small, the angular velocity would be high. The execution will be continued with the angular momentum. The rotation of the thigh with the calf held together must continue until the thigh is oriented straight ahead at the sagittal direction. Now the calf starts to extend itself toward the target. Because the calf left the contact of the thigh, the moment of inertia will be large and the angular velocity will decrease.

The loss of the angular velocity will be minimal for a very short time. At the time of impact, the angular momentum will change to angular impulse. At this phase of the kick, we speak about *impulse–momentum relationship* that is derived from Newton's second law, which shows that the impulse of force is equal to the change in momentum of the body/object.

Prior to describing the impulse–momentum relationship, the author will rewrite Newton's first and second law related to angular motion as a remainder for any calculations used in angular motion:

- For Newton's first law. The angular momentum of an object remains unchanged unless a net external torque is exerted on it. $(\Sigma T)(\Delta t) = \Delta(I \cdot \omega) \rightarrow 0 = \Delta(I \cdot \omega)$. Controlling angular momentum, you need to speed up or slow down angular velocity.
- For Newton's second law. If a net external torque is exerted on an object, the object will accelerate angularly in the direction of the net external torque, and its angular acceleration will be directly proportional to the net external torque and inversely proportional to its moment of inertia.

Impulse–Momentum Relationship:

Angular impulse (DL) = change of angular momentum (ΔL) = $I\Delta\omega$.

$$(\Sigma \mathrm{T})(\Delta t) = \Delta(I \cdot \omega) = I\delta\omega \rightarrow \Sigma T = I(\Delta\omega/\Delta t) \rightarrow \Sigma T = I \cdot \omega$$

Let us continue and dissect the roundhouse kick execution before the impact and at the time of impact. Recall that there will be a minimal loss of angular velocity before the impact, but at the same time the moment of inertia will be larger. This change by having a greater inertia for a very infinitesimal short time will not affect the force of penetration.

At the very beginning of the kicking process as has been described, the inertia is small and the velocity is high. So, even formally the inertia should be high before the impact, the angular velocity will still be high because the centripetal force acting on it, which maintains a good acceleration. Recall that every rotational motion has an acceleration because of the change of direction. So, knowing this fact the roundhouse kick will remain efficient.

An example from a karate kick motion is provided. The following physical properties should be calculated: torque, moment of inertia, kinetic energy, work, power, and their relationship to each other (see Figure 9.5).

Here are the physical properties related to Figure 9.5: $r = 0.48$ m, mass of the calf (m) = 3 kg, $\varpi = 0.4$ s, from the initial position of the calf to the final position, $\theta = 90°$. r is the radius from the axis of rotation or distance and ϖ is the average angular velocity. The foot is not included in the calculations. As a remainder, here are the different measuring units: 1 J = 1 N · m are for work, energy, and torque; 1 N · m/s = 1 J/s = 1 Watt (W) is for power.

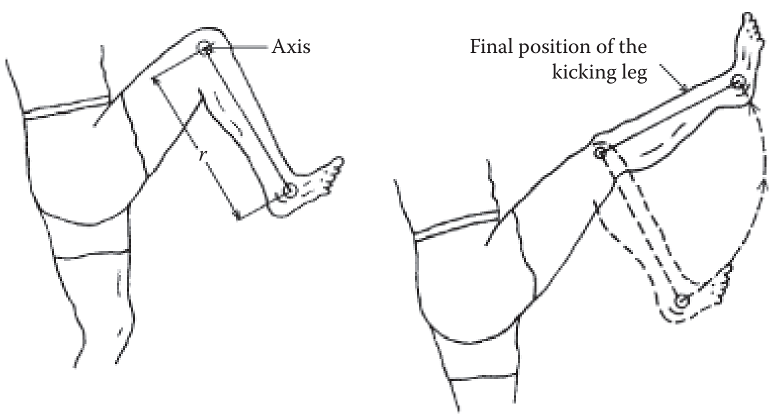


FIGURE 9.5

Calculation of the torque $(T) = \mathrm{N} \cdot \mathrm{m} = m \cdot g \cdot r$ (cos 90°) = (3) (9.8) (0.48) = 14.11 J. cos 90° = 0.

Moment of inertia $(I) = m \cdot r^2$ $(\mathrm{kg} \cdot \mathrm{m}^2)$ = (3) (0.48^2) = 0.69 $\mathrm{kg} \cdot \mathrm{m}^2$.

Rotational kinetic energy $KE_{\mathrm{rot}} = 1/2\ I \cdot \omega^2 = (1/2)\ (0.69)\ (0.4^2) = 0.055$ J energy.

Average work $(\overline{W}) = T, \theta$ = (14.11) (90°). For 90°, we use rad 1.57, then W = (14.11) (rad 1.57) = 22.15 J.

Average power P = work/time. Then, P = (22.15)/0.4 s = 55.37 Watt.

9.9 STUDY QUESTIONS

1. A laterally extended arm is ready to hit the opponent's face with a ridge hand strike (*Haito-uchi*) with a force of 85 N (see Figure 9.1). The force is exerted at a distance of 0.78 m from the glenohumeral axis (shoulder) and is stopped by the opponent's blocking arm at the 0.37 m (counted from the opponent's shoulder). 0.78 m represents the total arm length. The strike is exerted in a circular manner. What is the total force?

2. A force of 125 N is exerted at a distance of 0.5 m from the axis of rotation. What is the resulting force?

3. Presuppose that an Akidoka performs a throwing technique named entering throw—negative (*Irimi-nage*). If the attacker (*Shite*) executes the technique fast and correctly, he can generate an angular velocity of one full revolution in 2–3 s. Find out the angular velocity (ω).

4. A rod of negligible mass with total length 2 m has a small spherical object of 2 kg mass fixed on each end of the rod. The axis of rotation is perpendicular to it and is in the middle of the rod. The ω of the rod is 8 rad/s. Find out the moment of inertia and the angular momentum.

5. a. A karateka hits with the technique of ridge hand strike *(Haito-uchi).* The total rotational distance by this arm can describe 180°. The total arm length, which is the moment arm (r) = 0.70 m, the ω = 3.14 rad/s, and the total arm mass = 3.50 kg. The velocity is constant, 0.9 s. The axis of rotation is at the glenohumeral joint of the shoulder. Calculate the moment of inertia, angular momentum, and torque.

b. If the karateka hits with a round punch (hook) *(Mawashi-zuki)*, then the moment arm is shorter, approximately 0.35 m, because the arm is bent to 90°.

6. Consider a judoka executes a somersault, more precisely a forward roll (*Chugaeri* in Japanese). In this technique, the judoka should be considered as a solid cylinder (not taking into consideration the width of the judoka's shoulders), with the radius *(r)* = 0.156 m, the mass = 70 kg, and the rolling going along the "*X*" axis forward. The axis is oriented transversal and is considered as the lower abdomen area. The rolling motion has a uniform velocity = 0.3 s.

   Find out the radial force $F_{\text{radial}} = m \cdot r \cdot \omega^2$ or $m \cdot v^2/r$. We will use the second equation. 0.156 is the radius taken from the circumference of the entire stomach area. Because the rolling body never makes up a complete circle, that is why the radius of 0.156 m is an approximate number.

9.10 SUMMARY

In this part, Chapters 6 and 7 dealt with velocity and acceleration under linear and circular motions. A small summary described how to use different calculations to find out distances and displacements, including trigonometric calculations for different angles of the velocity in case.

Chapters 8 and 9 occupied a major portion of Part III, describing the dynamics of biomechanics. The majority of descriptions focused on the description of the forces, equilibrium, momentum, inertia, power, energy, and work.

Chapter 8 focused on forces and its manifestation such as work, energy, and power. Chapter 9 described and explained the angular momentum, focused on moment of inertia, torque, impulse, impact force, and the relationship between energy and power. A clear explanation between force and power has also been described.

IV

Martial Arts Biomechanics

OUTLINE OF PART IV

Part IV describes many different martial arts. The author initially was thinking of grouping different martial arts related by their movements, such as linear, angular or more force, speed, or skill related to the art. The author finally decided to group martial arts as they are (judo, Jujutsu, karate, boxing, sword techniques, etc.).

Basically, there are three categories that are pretty distinct from each other: (1) throwing arts, (2) striking and kicking arts, and (3) sword and knife arts. Each of these groups emphasizes on certain technical characteristics. These characteristics or—simply said—techniques are herein described, analyzed, compared, and emphasized on two or more biomechanical aspects, which is more relevant to the respective art.

The vast majority of the books that describe the biomechanics of sport techniques deal more with those sports that are related to "speed and distance," not neglecting force, stability, friction, impulse, BoS, CoG, inertia, momentum, and so on. These sports are track and field (running, throwing, and jumping), swimming, field sports (soccer, baseball, football, etc.), volleyball, ice hockey, basketball, kayak, canoe, and so on.

Described very seldom are the biomechanics of boxing, wrestling, fencing, or more importantly one of the so-called classical martial arts such as judo. What can be the reason for this? The reason is twofold: the first is that martial arts are not as popular when compared with almost any other

sport or even physical fitness. The second reason, and the most significant/important, is that martial arts are very sophisticated when compared with many other sports with gymnastics being a notable exception.

In many sports, biomechanics books on running race distance are analyzed where speed or velocity is very important. Also, the runner's stride (length, frequency, etc.) is examined biomechanically. It is easier to analyze or describe a running race when compared to a throwing action such as a *Kote-gaeshi* (wrist out-turn) throwing technique from Aikido, where the opponent's wrist exhibits multiple 3-D action. In this technique, the defender first must lose his balance, and then regain it in order to execute the technique. The author's opinion when describing and analyzing martial arts biomechanics must be under the umbrella of spinning/turning techniques under the influence of the force (voluntary or involuntary), velocity, equilibrium, mass of the martial artist or the mass of the weapon, impulse and contact forces, and so on.

In this book, the focus of analyzing the biomechanics of the different martial arts will be on the anatomical leverage, the practitioner and his opponent force, and explanation about which major muscles have the role of sustaining the correct technical executions. The author introduced a brief content for each chapter explaining about each art and where the biomechanical focus will be.

SUMMARY OF PART IV

Recall that it has been briefly mentioned that it is difficult to find examples in martial arts related to velocity, acceleration, momentum, work, energy, power, and so on in angular motion. These physical properties are executed very briefly and the calculation of these properties does not give us convincing final results. Sports such as track and field, hockey, diving, golf, soccer, baseball, football, and so on all are involved with "time," which is directly or indirectly used in the equations of different physical quantities.

The time occurs for a longer period than for martial arts, where almost all the actions are executed in a very short time period. In the previous chapters, the author described some examples from everyday life and from those sports mentioned before. By describing such examples the author gave an example from a martial art, which is compared to another sport (not martial art), for example, jumping in track and field.

Because the mechanical (technical) movements in martial arts are executed extremely fast, the author will focus on the dynamics and less on

the kinematics. Because of the vastness of the martial arts techniques, the author will also describe two or a maximum of four techniques and most importantly the most used techniques (by the athlete) of the martial arts being described.

Martial arts are contact sports. The author introduced and used in this book different terminologies for the word "contact." *Permanent contact/link* is when the athletes hold each other, such as judo, Jujutsu, Aikido, sambo (Russian Judo), and wrestling. *Semipermanent contact/link* is when the athletes have contact by touching each other, such as karate, Taekwondo, kung fu, kick-boxing, and boxing. The last category is *contact through objects*, such as Olympic fencing, knife defense, Kendo (fencing with the bamboo sword), Naginata-do (fighting with halberds), and Kali (Philipino stick fighting art). The last three arts of *contact through object* will only be mentioned and not described in this book.

By summarizing these martial arts under the *permanent contact/link*, the author will describes the defender's (judoka who is thrown) role as well as the attacker's role with the meaning of mechanics and physics. Under this category, the two opponents are as one almost all the time. For this reason, the author mentions if the attacker's or defender's role will be analyzed.

The attacker's roles will be more prevalent under the *semipermanent contact/link*. The defender's role can play an active part under the *contact through objects* description not just defending efficiently, but also counterattacking efficiently.

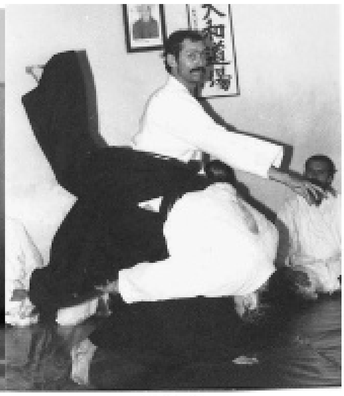
The author would like to mention for the readers that in this book, many so-called minor techniques that are important for a specific art will not be described. These so-called minor techniques can be found in any specific martial arts book. As an example, in judo, there are many different kinds of falling techniques, but the author chooses only a few of those techniques that are most important from a biomechanics point of view.

Note: (a) The reader should know the following terminology: Attacker is the person who executes the technique against the other person. Defender or opponent is the person who will be thrown, taken down, or be subdued; however, the roles are changing in the case of a counteraction of the defender, which in this case becomes an attacker. (b) In some cases, the attacker is named (A) and the defender is named (B) or (D). For technical terminology, the author uses English and Japanese language interchangeably. The Japanese written language is said to be the Romanji; in other words, Roman letters are used for a better understanding.

CHAPTER 10

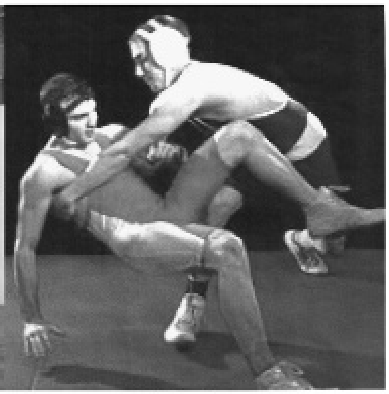
The Biomechanics of Throwing Arts

Judo



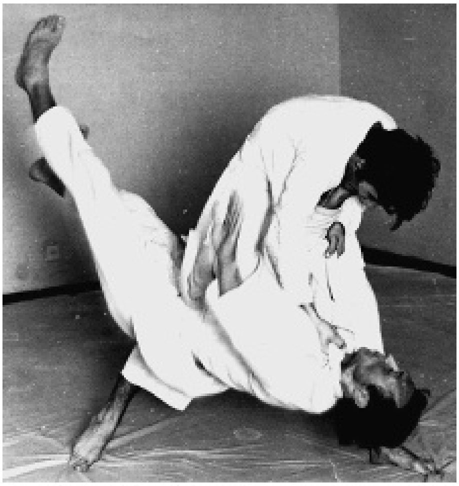
Aikido

Sambo



Wrestling

10.1 JUDO: THROWING TECHNIQUES (*NAGE-WAZA*)



Body drop (*Tai-otoshi*)

10.1.1 Anatomophysiological Considerations

Judo is a very dynamic sport. Classified by technical-physical effort and physiological participation of the athlete, judo can be considered a sport activity where the main effort is concentrated on strength/force and speed under the endurance regimen.

The psychological participation is somewhat reduced in comparison to other sports such as fencing, which is based in a split second decision. In judo, the decision is based on many technicotactical combinations, which can be easily learned during typical trainings. It is not to recognize what to do in a split second but to recognize if there is a possibility to execute a combination suitable for a specific attack. For this reason, the time to execute such a decision is longer than in fencing.

Under anatomical consideration, the judoka has a mesomorph body type, which is characterized with a well-built musculature. Wrestlers, boxers, canoeists, and javelin thrower also have such musculatures. The judoka's leg, especially the thigh muscles, are much better developed than that of the wrestlers and boxers.

10.1.2 Objectives

After reading this chapter, you will be able to understand and do the following:

- Describe the major biomechanical characteristics.
- Name the major muscle groups and their actions during different types of technical executions.
- Explain the different motor skills related to different types of technical executions.
- Explain the different kinematic chains and their actions (agonist and antagonist muscles).
- Explain the different leverages used for different techniques and their mechanical advantage, if any.
- Describe CoG and BoS of the judoka in static and in dynamic position.
- Compare different technical executions and give your opinion about the efficiency or inefficiency of the mechanical features of the particular technique.

10.1.3 Classification of Throwing Techniques

The author outlines the classification of the throwing techniques for the reader to better understand the vastness of the judo techniques existing at this time. In the world, there are different recognized classifications (systems). One that is the oldest and most used is the system of "five groups of techniques" (*Gokyo no Waza*). There are other classifications recognized by the International Judo Federation such as the former Judo Olympic Champion Dutch Anton Geesink's system, the Japanese Kawaishi's system, and others.

The *Gokyo no Waza* system of throwing techniques includes five groups, each contains eight throwing techniques. This technical system is set up for obtaining the different colored or beginners class/belt (*Kyu*) in judo. *Kyu 6th* is for a beginner and goes until *Kyu 1st*, which is one step before the *Shodan* or first degree black belt.

This system that is widely accepted by everybody in the world unfortunately is not set up logically because of technical difficulty. At this time, we are not interested about this issue. Furthermore, the throwing system is classified into other subclassifications:

- Standing techniques (*Tachi-waza*)—throwing executed in a standing position where we have three subgroups of throwing techniques:
  - Hand techniques (*Te-waza*)—where the techniques are executed primarily with the arms.

- Hip techniques (*Koshi-waza*)—where the techniques are executed primarily with the hip.
- Foot and leg techniques (*Ashi-waza*)—where the techniques are executed primarily by the foot and the legs. For those who are not knowledgeable in judo, it should be stated that any technique is finalized by the arms even if the technique is under the classification of *Ashi-waza* or *Koshi-waza*.

- Sacrifice techniques (*Sutemi-waza*)—throwing is executed mostly by the defender (*Uke*) lying down on the mat (*Tatami*) and throwing the opponent's body over the defender. Here are two subdivisions:
    - Supine sacrifices techniques (*Ma-sutemi-waza*)
    - Side sacrifices techniques (*Yoko-sutemi-waza*)

10.1.4 Biomechanical Principles in Judo

1. The judoka is never at rest. All the actions are dynamic. At the very beginning of a judo contest, a judoka fights for getting a good grip (*Kumi-kata*). During the fight, for getting a good grip, there is a constant change of equilibrium by losing and regaining.

2. There are permanent strength/force applications (push and pull) during the free fight (*Randori*) or competition (*Shiai*). The upper part of the body, especially the arms (biceps, triceps, forearms, and hands), brachioradialis, palmaris longus, the majority of the flexors, abductor pollicis and others, pectoralis minor and major, deltoid (all three parts), trapezius and latissimus dorsi, and others, are permanently involved.

3. Walking in judo is specific to the added leg stepping (*Tsugi-ashi*) where the foot movements are mostly executed laterally or diagonally, which are executed in a synchronous movement with the participating opponent.

4. Both fighters try to keep their CoM as low as possible to maintain a good BoS. A tall judoka prefers to execute more leg techniques, and a short judoka prefers to execute more hip techniques, where they can go deep by squatting under the opponent.

5. Calculations of forces (impulse, collision), energy, work, and power are mostly calculated under the linear motion of kinetics for the attacker. The forces for the defender who will be thrown are calculated mostly under angular kinetics equations.
6. Using equations under angular kinetics could be done if there is a clear-cut moment arm/radius from the axis of rotation.
7. Almost all the executions of the judo technique start as a linear motion, and then turn and finalize with an angular motion. The time moment between the linear and the angular execution is approximately less than 1.5 s. There is a twisting motion with the arms of the executants, which signals the beginning of the angular motion. If we take an example of a complete throwing action from the positioning (*Tsukuri*) to the last moment when the opponent hits the ground, the total time would be a little less than 2 s for an advanced judoka or 2–2.2 s for a beginner judoka. Basically, the total throwing time is represented by the preparation for throw (*Tsukuri*) and throwing (*Kake*) actions. From the total time of throwing, let us say 2.2 s, the twisting motion is there all the time of the execution of a throw. Certainly, it can be stated that it will take approximately 75–85% of the total throwing time.

It is important to mention that from the *Gokyo* system of 40 throwing techniques, only six techniques can be considered as a linear execution, but in these executions, we must consider only a *point mass* from the attacked leg and they are: forward foot sweep (*De-ashi-barai*), large inner reap (*O-uchi-gari*), small outer reap (*Ko-soto-gari*), small outer hook (*Ko-soto-gake*), and small inner hook (*Ko-uchi-gake*). Finally, there is another technique named scooping throw (*Sukui-nage*). In this technique, the attacker's execution is linear but the defender's motion is rotational.

Natural posture (*Shizentai*): This position is similar to a man who stays erect. Feet are parallel with the toes oriented easily outward, and heels are about 30 cm apart. Judoka very seldom hold each foot parallel. One foot is almost always is forward position. Arms are hanging down in a relaxed manner. The CoG is near the waist. Females have their CoGs at 53–56% of their standing height and males have their CoGs at 54–57% of their standing height. Walking in judo will not be described in this book.

10.1.5 Judo Throwing Techniques Executions

In order to throw an opponent, there are three important technical motions that are inseparable:

- Off-balancing the opponent (*Kuzushi*). The athletes have contact with each other only with their arms (seldom with their legs).
- Preparation for throw/positioning the hands (*Tsukuri*). At the positioning time, the executor/attacker has contact with the opponent with his arms, foot/leg, or hip/shoulder.
- Execution of the throw (*Kake*).

The meanings of these three technical requirements are as follows: *Kuzushi* prepares the judoka for the easiness of throwing. *Tsukuri* prepares the judoka for a successful finalization (*Kake*) of the technique. In order to throw or to be thrown safely, your partner/opponent (both judoka) must learn the "break-fall" (*Ukemi*) techniques.

10.1.6 Biomechanical Analysis of the Techniques

10.1.6.1 Break-Fall (Ukemi)

The art of falling is very important for preventing injury because the contact with the ground can be very painful and dangerous. For a safe landing, the role of the participant who will be thrown is primordial; however, the role of the thrower is also very important. The thrower, usually the attacker (*Tori*), by holding the defender's kimono (different parts) will guide for safe landing of the defender.

Let us take as an example the "shoulder throws" (*Seoi-nage*) technique and analyze the attacker's role. By executing this technique, the defender falls from a distance of the attacker's shoulder level (Figure 10.1). When the attacker throws his opponent and the opponent is close to touching the mats, the attacker pulls back the defender's right lapel or sleeve a little bit and holds it with his left hand. In Figure 10.1, the action of pulling up the opponent can be seen clearly. This kind of action of pulling back the opponent is required for any throwing technique. If the thrower loses his balance, the pull-back action is lost and the opponent will land harder on the mats.

Learning the art of falling is most important for the judoka who will be thrown. There are many different types of falling, such as backward, sideways, forward falling, and forward rolling or somersault (*Chugaeri*). These

FIGURE 10.1 Judo throwing—shoulder throw (*Seoi-nage*). The arrow represents the pulling direction of the left arm (*Tori*).

falling techniques can be executed from supine, squat position, sitting, standing, and forward tumbling positions. We will analyze the forward rolling technique here (Figure 10.2a–e).

The *Chugaeri's* mechanical analysis is the following: You step forward with your right leg, and then incline your upper body forward (Figure 10.2a). Set your right palm on the mat oriented backwards (Figure 10.2b). Push the mat with your left foot.

This pushing makes the body roll. You will lean on your left side. During the rolling execution besides your right palm and your legs, which have contact with the mat first, the following body parts have contact as follows: right elbow, right shoulder, left side of your back and finally your left arm (which must be extended entirely).

Slap (hit) lateral on the mat at an angle of 45° from the body. Also at the same time when your arm hits the mat, your leg (left) will have contact with the mat. By hitting the mat with your arm, the shock from the ground reduces approximately by 80%.

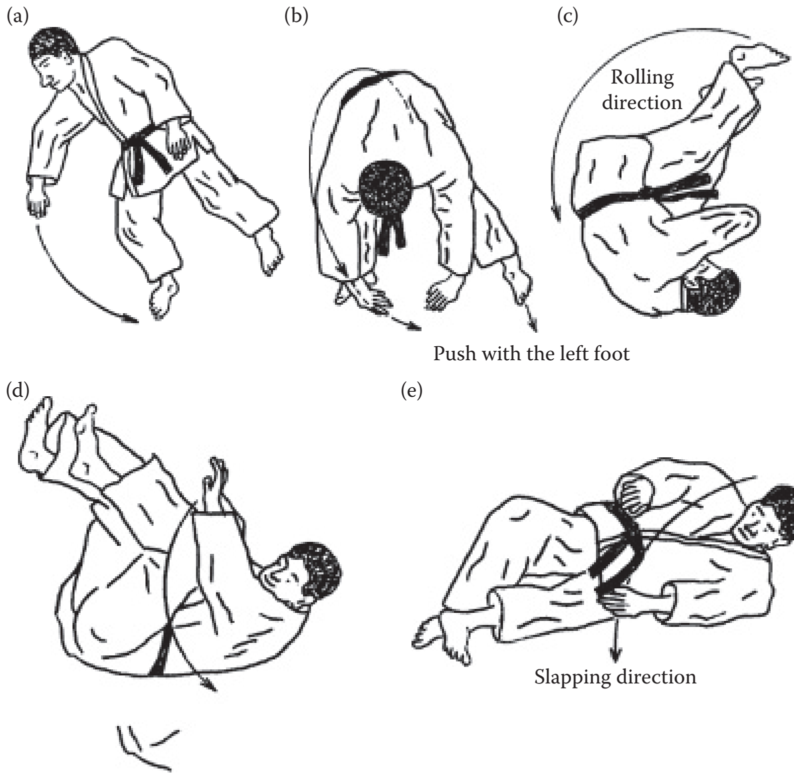


FIGURE 10.2 Forward break-fall (*Chugaeri*).

The reader could ask how can the hitting technique reduce the body's shock by 80%. The contact is always diagonal through your spine and by this way your spine has, at any moment, only one point of contact with your entire body mass.

This one-point contact of your spine helps to eliminate the serious risk of injury of the spine. Another fact is when you hit the mat almost all the time, you are on one of your scapula, which is a large bone and under that large bone there are no vital organs.

So, to resume the efficiency and safely land by hitting with one or both arms and by landing on one or both scapulae, the judoka's body will be safe. When landing on the mat, the judoka must hold his head in a forward flexed position.

Note: Top judoka tries to avoid hitting with the arms. They are so well conditioned that the chance of injury during falling is reduced almost to zero percent.

10.1.6.2 Observation of Physical Properties of the Break-Fall

In case of falling (thrown by the opponent), we deal with the velocity, kinetic energy, and impulse (impact force). To calculate the velocity of the opponent (defender) who falls from a certain level, for example, from the attacker's shoulder, we use the equation $v = a \cdot t$. Here, the acceleration given by the force exerted by the thrower is neglected and we use the acceleration of the force of gravity and multiply it by the time of the falling of the judoka when he hits the ground. For the *KE*, Joule, and impact force, we use the adequate equations that were described earlier in this book.

10.1.6.3 Off-Balancing (Kuzushi)

Before off-balancing, your "hand grip" (*Kumi-kata*) positioning has an extremely high importance. There is a universal gripping position that every judoka knows. Suppose that you and your opponent are right handed. Stand face to face. Both of you grab your opponent's left collar with the right hand a little bit under the clavicle area and with your left hand grab the right sleeve outside or above the lower part of the triceps muscle.

Your opponent should or could have the same grip. Of course there are many variations that are not described here.

After the hand grip is assured, try to off-balance your opponent. The mechanical action is the following:

Assume that both of you have the right-handed grip and both of you stay in a natural posture position (*Shizen-tai*). You start to pull your opponent's right sleeve upward and forward with your left hand. At the same time, with your right hand, push up only (do not pull forward) the collar of your opponent. Your right arm triceps muscle has an eccentric action where the mechanical work done is negative ($W = F \times d$), where d = distance. Pushing up the collar does not assure that there is any d; that is why we have a negative work. The major action is by your left hand because you can use the mechanical advantage of the lever offered by the opponent's right upper arm. Holding the sleeve helps the action.

It is important to mention that if your left hand has a grip much lower than the opponent's elbow, then the mechanical advantage by using a lever loses its effect because in this case you do not succeed in pulling the opponent; instead, you will only move his arm. You no longer have a lever such as the upper arm, but you have a movable kinetic chain (upper and lower arm). The off-balancing will not be successful. The described off-balancing execution is mostly used for hip techniques.

Another important action for off-balancing is the twisting motion of your left hand. This kind of execution is used mostly for hand/arm and leg techniques executions.

10.1.6.4 Positioning (Tsukuri)

The following descriptions by mechanical means will mostly analyze the *Tsukuri* and *Kake* parts of the following techniques. In preparation for the throw, the positioning is important. The attacker must position himself close to the defender as the technique requires. Also, the positioning must be done in a timely manner. If one of these two factors is missing or not correct, the throwing will not succeed. The author will describe three techniques, one for each category of throwing (hand, hip, and foot techniques).

These three techniques are: hand technique—arm wheel (*Te-guruma*), hip technique—springing hip (*Hane-goshi*), and foot technique—lift-pull foot sweep (*Harai-tsuri-komi-ashi*). For each technique, the mechanical description will be the positioning (*Tsukuri*) and the execution (*Kake*).

10.1.6.5 Arm Wheel (Te-guruma)

This technique is not under the *Gokyo* classification. It is a counter technique. In the following figures, the attacker (*Tori*) intends to execute a (*Harai-goshi*) named "hip sweep." The right leg of the *Tori* would execute a backward swing/sweep against the defender's (*Uke*) right thigh lateral side (Figure 10.3a). At this moment the *Uke* has his opportunity to counter the attack. Technically, it is not complicated; however, the judoka needs to be strong because he must pick up the opponent approximately to the chest/shoulder level.

In this technique, there are no off-balancing (*Kuzushi*) and no positioning (*Tsukuri*); it is only the throwing (*Kake*). If we talk about the positioning, it is an extremely short time when the defender would set his left palm (see Figure 10.3b) under the attacker's right thigh close high to the groin area. The attacker has his back against the defender. The defender holds the attacker's right collar tightly. He does not make a considerable effort, except his right forearm flexors, which are squeezing the collar.

At this time the defender squats deeply behind the attacker and with his left hand, which is now under the attacker's right thigh, grabs the attacker's pants in the thigh area. However, instead of grabbing the pants,

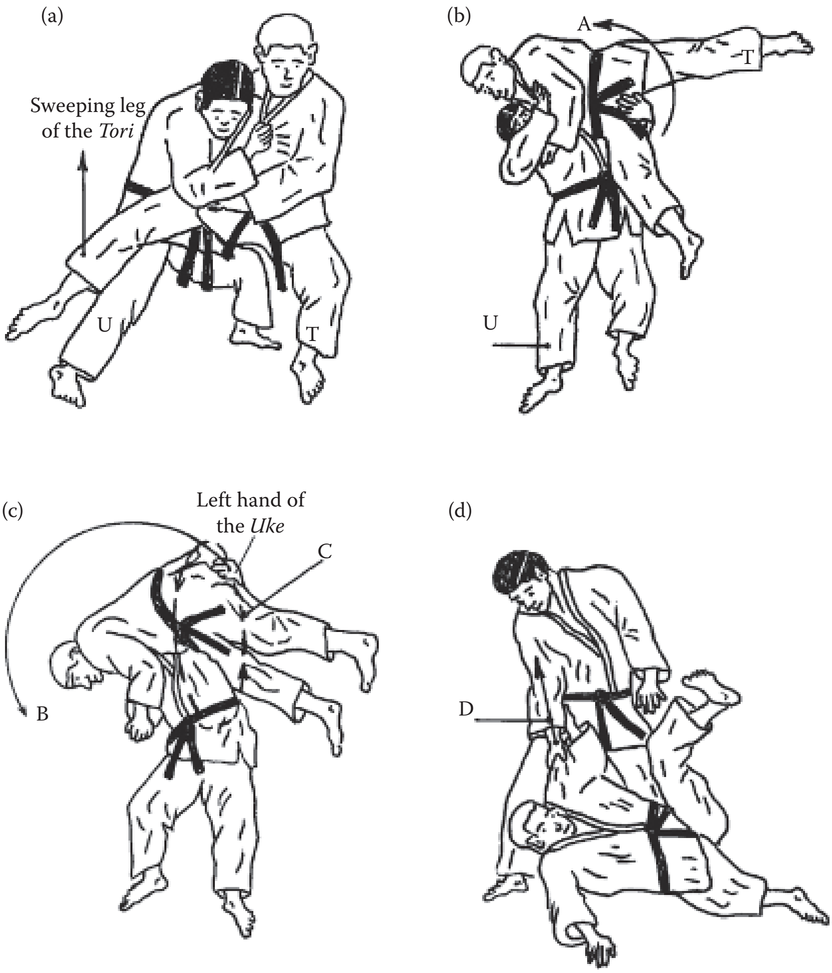


FIGURE 10.3 Arm wheel (*Te-guruma*). U represents the *Uke* (defender). T represents the *Tori* (attacker); the T can be seen on the left leg of the *Tori.* A represents the sagittal axis of the initial rotation. B represents the frontal axis of rotation. C represents the vertical axis of rotation (shown with the discontinuous line). D represents the action of pulling up the opponent for ease of landing.

the defender can surround the thigh with his open palm or simply tightly close his fist close to the groin area of the attacker. By tightly squeezing his left fist, the defender can tighten his forearm muscles, which will have a major role in lifting the attacker. The defender's left forearm should stay in a flexed position with the upper arm, approximately 90–105°. The motion of squatting can be considered the *Tsukuri*.

Both thighs of the defender make a considerable static effort in principal with the quadriceps muscles. The defender lifts up his attacker high about his upper chest/shoulder area with the following action:

The defender extends energetically his spine and especially his neck backwards with the motion of lifting the attacker. The defender's left arm mostly holds the attacker tightly to his body. The defender's right arm pulls the attacker even higher than the shoulder level.

During the time of lifting the opponent, the working muscular chain executes plantar flexion of the foot, extension of the leg and the thigh, and these muscles are muscles of *tibialis posterior, peroneus brevis* and *longus, flexor digitorum longus, gastrocnemius,* and *soleus.* Action about the thigh muscles are *rectus femoris, vastus medialis, intermedialis* and *lateralis* (*quadriceps*), and *tensor fasciae latae.* Muscles of the hip execute extension during lifting of the opponent. The muscles are *gluteus maximus, biceps femoris* (*long head*), *semitendinosus, and semimembranosus. Adductor magnus* (*posterior head*) assists for the extension of the thigh.

Some of the extensor muscles of the dorsal part of the body are *erector spinae* (*spinalis*) and *transversospinalis* (*semispinalis* and *mutifidus*). There are some other muscles that have a secondary role of extension of the vertebral column such as the *longissimus thoracis, cervicis,* and *capitis.* During the lifting of the opponent, there is a strong vertical momentum, where the mass and the velocity equally have a very important role. The vertical velocity must prevail over the mass in order to ease the flipping/turning of the opponent for the throw. Refer later on the execution of the *Te-guruma* (Figure 10.3a–d).

10.1.6.6 Execution of the Throw (Kake)

When the opponent reaches the highest level during the throw, the thrower/defender (who now becomes the *Tori*) flips the opponent mostly using his right hand with a strong twisting motion. With this twisting motion, the opponent will have a very good momentum and he will be oriented with his back toward the ground during his brief fly. From this position, the thrower can (if he would like) drop his opponent to fall onto his back in order to score a good point.

However, the thrower should guide the opponent toward the ground by using his right hand controlling the opponent's fall. During the throw, the attacker mostly works on his equilibrium because the weight of the

opponent mass, which could intervene the attacker to lose his balance. See Figure 10.3a–d, which shows the *Te-guruma* technique.

10.1.6.7 Observation of Physical Properties of the Te-guruma Technique

For the execution of the arm wheel technique, the most important physical attribute is the muscular strength of the executor. The defender's *PE* from a standing position will turn into *KE* with the motion of squatting down in order to lift up his attacker. During the squatting, the defender's action is negative. Here, we should note the gravity (–9.8 m/s^2); however, this action happens under an extremely short time. During this short interval, the *PE* is stored as elastic energy. Note: the torque will be calculated for the attacker, who will be thrown by the defender.

The correct calculation for the torque of the attacker or even for the moment of inertia will be only approximate because there are three very short kinds of rotations through different axes such as sagittal, frontal, and vertical. The author chooses the sagittal axis as an example. For the moment of inertia, the spherical calculation can be used as an example.

At the time when the defender picks up the opponent, the *PE* will transform into *KE*. The grand reaction force (GRF) is very large because of the masses of two judoka. The defender deals only with the static friction force. If we want to describe the torque of the opponent who is thrown, there is no clear-cut moment arm and more specifically there is no clear-cut axis for rotation of the judoka. The defender (*Uke*) defends himself by throwing the attacker (*Tori*).

To calculate the torque or moment of inertia of the judoka who is thrown, in our case, the attacker (*Tori*), we would need a clear point of the axis of rotation of the body. It is correct if we assume that for the calculations of the torque we must establish an axis of rotation of the body in case, which is the attacker's body (the person who is thrown). We will use the attacker CoM, which is approximately at the lower abdomen level (Figure 10.3b). However, if we look at Figure 10.3c, then the CoM moved higher and is approximately at the attacker's buttock.

Looking again at Figure 10.3b, the axis of rotation can be established through the sagittal axis direction; however, looking at Figure 10.3c, the axis of rotation can be established through the anteroposterior (lower abdomen) frontal axis of the body. This rotation through the anteroposterior axis can happen for a fraction of a second and continue the rotation of the body will change into longitudinal (vertical) axis of rotation (Figure 10.3c does shows this action with the dotted line C). The thrower's ener-

getic twisting and rotation action of his right arm makes the opponent turn around his longitudinal axis and finally to be down on the mats.

Because the body will be thrown not only in one direction but in a 3-D direction by a twisting motion, the author decided to use an imaginary central point/CoR for the lower part of the body (pelvis). From this central point, the radius using the diameter of the lower part of the body will be calculated.

In order to calculate the attacker's body torque, we must know the moment arm (radius) of the rotating body. We know that the entire body of the attacker rotates. But because the attacker's legs can slow or speed up the rotation by having his legs far or closed to each other, also close or far from the CoM, that is why we will concentrate to a reduced segment mass of the body and this will be the area of the lower part of the trunk (pelvis) and including the buttocks.

According to many authors, for a 70 kg man, the mass of the lower part of the pelvis can be approximately 7.8–8.9 kg or even more. In our case, the circumference of the body is approximately 100 cm, which we divide with 3.14 (π) to receive the diameter of 31.80 cm. Now, we divide the diameter by 2 (31.80/2 = 15.9 cm or 0.159 m), which will be the moment arm (radius) or the distance from the center of rotation to the periphery of the rotating body. To calculate the torque we will have $T = \mathrm{N} \cdot \mathrm{m}$ [(8.9 kg) (9.8 m/s^2)] (0.159 m) = 13.86 N · m. The reader should consult different publications where one can find the approximate weight of body segments.

The aforementioned calculation for torque is theoretically correct but we know that the force (N) can act perpendicularly to the axis of rotation or the acting force should have a straight line to the axis, which could include different angles. In our case, there are no clear-cut force acting line(s).

You must keep in your mind that the targeted area is not the entire body, but only the restricted area of the lower part of the trunk with the buttocks. The importance of calculating the moment of inertia will show us the resistance to change the body's angular velocity. Earlier, it has been described that the moment of inertia of a body depends on the distance between the axis of rotation of the body/mass and how far this body is located from the center of rotation. To calculate the moment of inertia as a reminder, the equation is $I = \Sigma m \cdot (r^2)$. Σ represents the total sum of the particles, r represents the radius from the axis to the body's periphery that rotates.

Note: The rotating body is not cylindrical; instead it is elliptical, but because the rotating body goes instantly through with three axes, the author chose the cylindrical shape for an easier calculation.

We want to calculate the moment of inertia for a small segment area (pelvis) of the large rotating body; we should use the equation for symmetrical and/or uniform rigid bodies/objects (consult Section 9.6). In this case, we choose the pelvis to be represented as a solid cylinder having the axis at the middle of the cylinder (vertically) (which is 2 radius). Then the equation for the moment of inertia for a 70 kg man about his pelvis will be $I = 1/2m \cdot r^2$. Then, $(I) = 1/2(9.8\text{ kg})(0.159\text{ m})^2 = 0.122\text{ kg} \cdot \text{m}^2$.

In our case of the *Te-guruma* technique, it is better to calculate the radius of gyration than to use the calculation of (I). The word of gyrate (Greek) means rotate, spiraling. Because of the calculation of inertia we must have a clear-cut so-called "point mass" and not a large mass as in our case.

The radius of gyration (k) is not the same as the distance to the segment of the CoM. Also, it is not represented by the value squared. The value of k magnitude is different for different axes of rotation. The radius of gyration represents a length that is the distance between the axis of rotation and the point at which the body mass is distributed and has the maximum effect.

To explain better, k represents the horizontal distance between the axis and the point that represents the "sum" of all separate moments of inertia of the parts of the body mass. Calculate $k = 1/2(I_{axis}/m_{segm})$ or calculate $(I) = (mass_{segm})(k^2)$. The k will represent meter or centimeter of the distance. In the literature of specialty, the (I) of a body about a given axis is often expressed by specifying the radius of gyration and the mass of the body. For the calculations of the $KE_{angular}$, $\overline{W}$, $\overline{P}$, see Figure 9.5 and its related calculations.

10.1.7 Springing Hip (*Hane-goshi*)

It is easy to learn this technique to some extent. The difficulty starts when the executor is ready to throw his opponent. The reason for this is that the attacker's right (if he is right handed) leg, which supports the opponent's right leg, could lose contact by slipping in or out, and by this the execution will be sloppy or the attacker can lose his balance and fall forward in a prone position.

10.1.7.1 Off-Balancing (Kuzushi)

For this technique, we recall the description for *Kumi-kata* described before. To execute this technique, the executor (*Tori*) can choose a different hand grip position. He will move his right arm under the opponent's left armpit and set his right palm on the left scapula. He can also grab the

kimono at the same place on the back of the opponent (over his left shoulder). This grip makes it easier to lift the opponent by getting closer to his body. Another variation is when the *Tori* can grab the opponent's collar at the back of his neck with his right hand.

To off-balance the opponent, the *Tori* will pull with his left arm the opponent's right arm straight upward a little bit and forward in a horizontal manner and at the same time he lifts up and a little bit forward the opponent collar with his right arm. In order for the off-balancing to be successful and further the finalization of the technique, the attacker should turn fast from a forward position (looking at the opponent) to a backward position [his back should be toward the defender's (*Uke*)].

The body turning is named (*Tai-sabaki*). Basically, shifting the body from one position to another, the attacker positions himself for the execution of the technique. There are many *Tai-sabaki* techniques in judo. Here, they will not be described. The attacker must know these body shifting techniques for almost any type of attacking technique. The defender must also know the opposing procedures against these body shifting techniques.

An important detail using the *Kuzushi*: The attacker must perform the off-balancing in such a way that the right leg of the defender should support more weight than the left leg. For this reason, the attacker should pull the opponent's right sleeve to the right (outside from the defender's body). In this way, the defender will have more weight on his right leg.

If the defender has more weight placed on his left leg or his weight placed uniformly in both legs, then the defender's right leg can waiver and the attacker cannot push back (sweep) because he can lose control on the defender's right leg (Figure 10.4a–d).

10.1.7.2 Positioning (Tsukuri)

The positioning starts with the body shifting (*Tai-sabaki*) technique (Figure 10.4a). The attacker turns his body (with his back) completely toward the opponent and continues to pull the opponent on his back (Figure 10.4b) or we can say the attacker positions himself under the opponent. His CoG should be much lower than the opponent's CoG. If the attacker holds this position for a long time, then this will be a detriment for finalizing the attack and will benefit the defender. The defender has an option to stop the throwing action by hooking with his right leg the attacker's right leg from the front (Figure 10.4b).

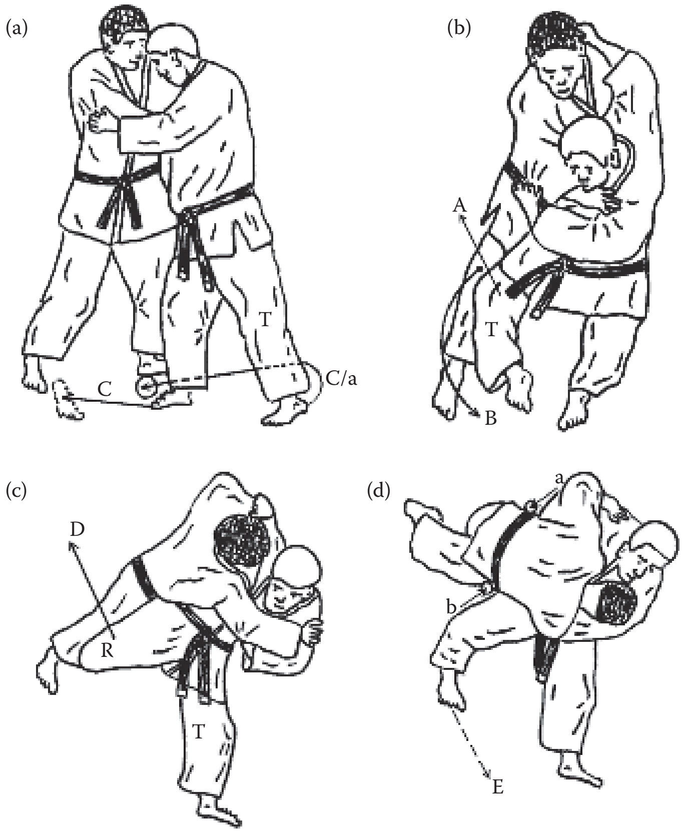


FIGURE 10.4 Springing hip (*Hane-goshi*). T represents the *Tori* (attacker). R represents the right leg of the *Tori.* A represents the right leg of the attacker that will push backward. B represents the right leg of the defender (*Uke*) that can block the attack of the *Tori.* C represents the *Tori's* right leg shifting position. C/a represents his left leg movement. D represents the attacker's right leg backward pushing action. E represents the returning action of the attacker's leg. (a and b) Represent the points of rotation of the defender. (c) Represents the rotation through the frontal axis. (d) Represents the rotation through the sagittal axis, which starts as a rotation through the vertical axis.

10.1.7.3 Execution of the Throw (Kake)

After the attacker positions himself under the defender's body, the action of the throw will start.

By now the attacker's right leg with the knee is flexed approximately 90–110° and set as a plateau in front of the defender's thigh and leg. So, the defender's right leg should rest on the attacker's bent (right) leg. The attacker pulls in continue forward with his left arm the defender's right

sleeve of the kimono. At the same time, he continues to pull up and twist the collar counterclockwise with his right arm to augment the off-balancing of the defender.

It should be mentioned that the attacker will never extend his right leg. The flexed leg should maintain the angle of approximately 90° or a little bit more (110°).

The attacker extends his left leg completely and inclines his upper body even more forward. When the defender's body is almost at the horizontal level, the attacker starts to throw the defender, by pulling and twisting the defender's right sleeve of the kimono and by pushing down the defender with the right arm at the collar level.

The action of the muscular chains for the attacker is the following (start from the left foot level): *plantaris* has a partial flexion motion of the ankle joint, *soleus, gastrocnemius,* and *tibialis posterior* also plantar flexes the ankle joint. The *quadriceps* muscle extends the knee joint. The hip has a strong flexion action with the following muscles: *sartorius, pectineus* (a wide and strong muscle), *adductor longus,* and *brevis.* When the opponent is thrown, but before landing on the mat, the attacker must pull back the defender a little bit for two reasons:

1. By pulling back the opponent by the kimono, the attacker assures that he has a good control over the opponent and he has the chance to continue his attack on the ground.
2. By pulling back the opponent through the kimono, the opponent will have a safe landing on the mat. Some accidents happen with beginner judoka who just lets the opponent to fly (not holding back the judoka by the kimono). In this case, the opponent will have a very hard landing or injuries can occur, such as muscle strains, ligament sprains, or even dislocations at the area of clavicle and/or neck level. See Figure 10.4a–d, springing hip (*Hane-goshi*) technique.

10.1.7.4 Observation of Physical Properties of the Hane-Goshi Technique

The major physical property is the strength, which is correlated with the attacker's body equilibrium. The calculation of the different physical properties never can be done exactly. Let's examine our technique the "springing hip." We know that this technique from the end of the *Tsukuri* to the end of the throw (*Kake*) involves a rotary motion. If we like to calculate the angular momentum, moment of inertia, and torque, the moment arm

and obviously the axis of rotation should be known. But where is the axis of rotation?

In this technique, like many other judo techniques, the axis of rotation and the moment arm are difficult to establish. In this case, we have to compromise and our calculations will be approximate. To calculate the moment of inertia of the attacker's hip and his entire right leg, we can use the parallel axis theorem (refer the calculation described in Chapter 9 and demonstrated with Figures 9.3 and 9.4).

We can establish the major axes almost exactly in the same manner as described in Figure 9.3. Calculating the angular momentum is more difficult than calculating the moment of inertia. Angular momentum $(L) = I \cdot \omega$; basically, the throwing happens on and about the attacker's hip and the upper part of his thigh. Again you should know that there is no clear-cut axis of the attacker; however, you can choose the two coxofemoral joints where the opponent will be thrown over mostly through the frontal axis direction (Figure 10.4b).

Another feature of this technique is that during *Kake* the opponent not only rolls over the attacker's hip but also over the attacker's right leg. In this moment, the throwing direction of rotation will change to the sagittal axis direction (Figure 10.4d). For this reason, the throw somewhat will slow down because there will not be a correct rotary movement in such a case of a rotating wheel.

For the angular velocity, you choose again the coxofemoral joint as the diameter of the pelvis, knowing that the middle of the diameter will represent the radius as the CoR. Further, you can decide about the point of the radius of gyration. This can be the axis (coxofemoral joint) and the end point will be the knee. The author will not enter into details to give an example. It has been described by several examples, so the reader should have the basic understanding of the examples described before in order to establish a correct reference.

10.1.8 Lift-Pull Foot Sweep (*Harai-tsuri-komi-ashi*)

This technique requires a very good equilibrium, coordination, off-balancing, strength, and timely stepping for its technical execution. It is a beautiful technique but rarely used because of its difficulty. To succeed in this technique, the prerequisite is the cooperation of the opponent. The steps before using any action (*Kuzushi, Tsukuri*) must be synchronized. The attacker must try to make sure that the opponent will follow his step's rhythm.

No opponent can be thrown if there is no synchrony between the two participants' steps. You probably will ask how could this happen in a competition where the opponents step as they choose. The only possibility for the attacker is to lure his opponent with different stepping maneuvers other than what he will do for the success of this technique.

In this technique, the attacker's body position and his muscular chain will be described. The role of the defender is absolutely minimal, almost reduced to zero percent.

10.1.8.1 Off-Balancing (Kuzushi)

From the view point of the attacker, he can execute this technique in two ways: (a) when he goes forward and the opponent goes backward and (b) when he goes backward and the opponent goes forward. The first solution is the most required. Suppose that both are right-handed judoka and both hold the conventional grip (*Kumi kata*), which has been previously described.

Both judoka stay with their right legs in the forward position. Now, the attacker initiates the stepping; he steps forward with his left leg and at the same time executes the *Kuzushi* by lifting the opponent mostly only upward with both arms. At the same time when he steps forward with his left leg and the opponent steps backward with his right leg, the opportunity arrives for the attacker to make his move for the *Tsukuri*. For a more successful execution of this technique, both judoka should stay with their left legs in forward position. This means an additional step.

It is important for the reader to know that the *Tsukuri* and the *Kake* should happen simultaneously. If we talk about the *Tsukuri* we should understand the following mechanical movements:

At the time when the attacker pulled up the defender's kimono for *Kuzushi* and he managed to set forward his left leg, he will push/sweep backward the opponent's right leg. At this time, the opponent finds himself losing his balance. See Figure 10.5a–d for the technique.

10.1.8.2 Execution of the Throw (Kake)

The *Kake* will happen by the following motions: The attacker with his left leg should sweep the right leg of the opponent backward and at the same time he augments his *Tsukuri* by pulling the opponent's kimono upward; then he will pull suddenly forward/downward and rotate the opponent counterclockwise. The attacker by pushing the opponent's right leg backward and by pulling the opponent with his arms forward/downward creates a *force couple* that will act as the throwing execution.

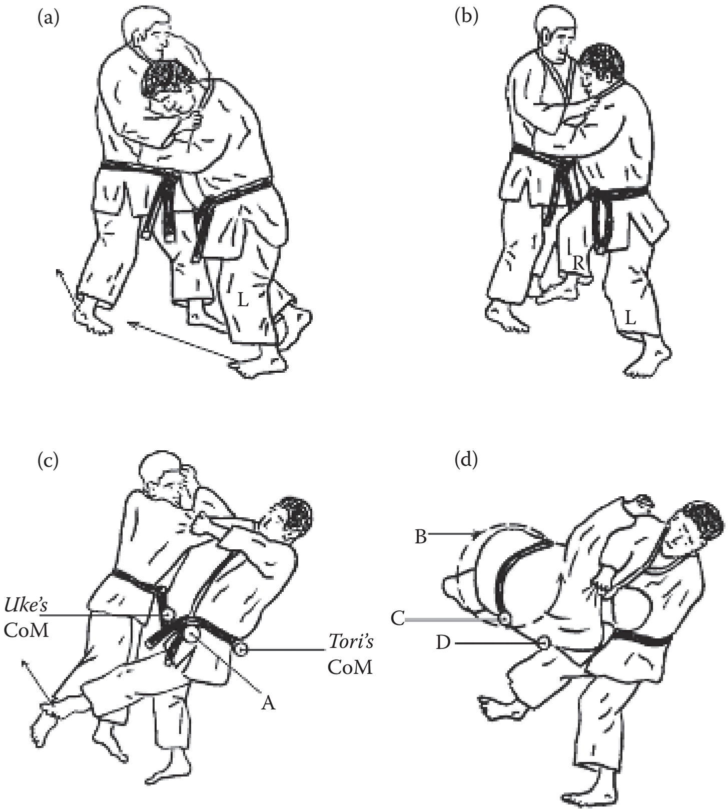


FIGURE 10.5 Lift-pull foot sweep (*Harai-tsuri-komi-ashi*). L represents the left leg of the attacker (*Tori*). R represents the right leg of the attacker. A represents the theoretical CoM of both judoka (see Appendix C for calculations of the CoMs of the two karateka). B the intermittent line shows the direction of rotation of the defender (*Uke*), which is CCW. C shows the right coxofemoral point of the defender. D shows the approximate contact point (knee) of the *Tori*. The arrows show the direction of action of the legs (to be the *Tori* or the *Uke*).

Recall that it has been mentioned earlier that in every judo technique and the final touch in any throwing technique, the arms have the most important role. In this technique, the leg sweeping action must work in unison with the arm's pulling action.

Here, we will describe the thrower's (*Tori's*) muscular chain from the lower body parts up to the belt of the judoka. *Tori's* supporting right leg: during the entire throwing, both muscle agonists and antagonists work for maintaining a balanced position of the attacker and for this reason

there will not be a complete extension of the muscles, but the right leg will hold a flexed position in this way. The foot and calf is flexed (dorsi flexion) approximately to 90–110°. The knee is flexed approximately 150° and the torso is aligned with the right thigh. Besides the different muscular actions described before, there is another muscular action of the attacker's left leg. The left leg of the attacker also describes a flexion between the thigh and the lower part of the torso of the body.

Here is the muscular chain of the anterolateral part of the body (flexors of the trunk); *external* and *internal oblique* and *quadratus lumborum* (Figure 10.5d), which flexes the trunk lateral. The lower part of the back muscles contributes to the extension of the pelvis, such as *intervertebralis.* The most important muscular chain of the shoulder and the arm are *trapezius* and *levator scapulae* (both are elevators of the scapula). *Deltoideus ventral part* and *pectoralis major* (both are horizontal adductors of the humerus). Ventral *deltoideus, pectoralis major, teres major, subscapularis* (are medial rotators of the humerus), and many other muscles contribute to the throwing technique.

10.1.8.3 Observation of Physical Properties of the Harai-tsuri-komi-ashi Technique

In the *Harai-tsuri-komi-ashi* technique, the arms and the sweeping leg have almost the same role. This technique characteristic is to create a *force couple.* Because of this we have to find an axis and/or CoR for the force couple. In this technique, the CoR is approximately at the same place such as the knees of both participants. However, the rotating body uses the knee as the CoR for approximately 75% of the total time of throwing. The remaining 25% of rotation of the defender (*Uke*) will change from his knee to the right coxofemoral area or a little bit higher (in case if we speak about right-handed attack for both judoka).

In this technique, speaking about *force couple* is not the realistic force couple; it had been described earlier when the two parallel forces acting in opposite direction should have equal magnitude. Here, we have approximately *force couples* in the following way:

In Figure 10.5c, when the attacker pulls the defender's kimono at the upper chest area, as a reaction to maintain his equilibrium, the defender will push back. Judging about the arms actions of both judoka, it looks like that we have a force couple. However, this is not the case because the forces are in the same direction (one is pulling and the other is pushing in the same direction).

Analyzing Figure 10.5c again, the action of the attacker's arm pulling backward and pushing with his left leg forward seems to be almost a good example of a force couple. However, the magnitudes of the two forces probably are not the same.

In this technique, just like the previous one, the throwing happens when the attacker is standing on one leg. The equilibrium is a primary factor for the success of this technique. During the short time of the off-balancing, the attacker's CoM is at the vertebral column lower lumbar area. The CoG of both judoka can be found between the two judoka (see Figure 10.5c).

The technique will succeed against the tall judoka. For a short judoka who has the CoM lower than a tall judoka, the sweeping with the leg will not be successful. The impact against the ground is considerable mostly because of the opponent's mass. Let us investigate the rotational momentum, work, and energy. As we know the angular momentum is proportional to the moment of inertia, which depends on the mass of the rotating object and how this mass is distributed relative to the axis of rotation.

As stated earlier, we basically describe the physics involved when the defender is thrown. In the following, we use both judoka (attacker and defender who is thrown). Why do we do this? The opponent (defender) clearly describes more rotary actions than the attacker, but we use the attacker's body parts as turning points, such as his left knee.

Analyzing the opponent who is thrown shows that the mass of the opponent is concentrated close to the axis of rotation (again to be stated that there is no clear-cut axis of rotation). The author takes his freedom to state that the axis of rotation of the defender is around the left knee of the attacker where the defender's initial angular rotation will be through the vertical axis (see Figure 10.5c).

As much the left leg of the attacker is lifted higher and the kimono of the defender is pulled forward and downward, the angular rotation will change its direction and will be rotated through the sagittal axis (see Figure 10.5d). Looking at points "C" and "D," it is realistic to say that any of these two points can be considered as the CoR or even a point between these two.

Also, the CoR is not inside of the pelvis of the defender but is outside of his body, particularly at point "C." For this reason, the author takes his freedom and will use point "C" as the CoR (right coxofemoral) from the pelvis of the defender.

In Figure 10.5d, it can be clearly seen that the CoM of the opponent is at the attacker's knee level. Because the CoM is close to the axis of rotation,

the moment of inertia is low, but the angular velocity is high. Earlier, it has been stated that the CoR of the defender is the knee of the attacker.

However, this CoR will be moved after the defender's both legs left the ground. In this case, the CoR will be higher approximately at the defender's coxofemoral area. Calculating the moment of inertia even if we take the turning point of the middle of the pelvis is not realistic because the human body is not a symmetrical and/or uniform rigid body. The body has legs and arms that are not kept at the same level (let us say close to the body). They are movable and for this reason the moment of inertia can be high or low.

For the sake of argument, theoretically, we can establish some parameters to calculate the moment of inertia. Here is the example:

The distance from the center of rotation (which is now at the coxofemoral area) we use the total body height of the defender and divide by 2, which gives us the radius (r). In this case, the effort arm or the radius is approximately half of the total body height, 0.9 m if the attacker is 1.80 m tall. Let us establish that the defender's mass is 70 kg.

For the calculation of the moment of inertia, we used the equation for solid geometrical shapes. In our case, we can use for the total body's moment of inertia a solid circular cylinder with the axis through center. We will take the "Y" (ordinate) axis, which is going through the middle of the cylinder taking into account that the middle is at 0.9 m. We also presume that the defender's legs are pretty close to each other and in line with the upper body. We will ignore the calculation of the arm movements that should be very close to the body.

Then, $(I) = 1/2(m)(r)^2$, where r is the radius. The axis is between one coxofemoral joint to the other coxofemoral joint. Our calculations for moment of inertia will be $(I) = 1/2(70\ \text{kg})(0.9\ \text{m})^2 = 28.35\ \text{kg} \cdot \text{m}^2$. This calculation is correct; however, the defender's body will not describe a complete circle because during and at the end of the throw, the circle becomes somehow twisted. For this reason, our calculation for the moment of inertia has an approximate number. *This martial art of judo technique really shows the difficulty in establishing any correct axis or any other parameter.*

Let us see what the work and energy of the defender will be. In our case, the rotational work $(W) = T\Delta\theta$. The angle (θ) can be measured by revolutions and by degrees, but it is usually measured by radians rad = s/r, where (s) is the distance (arc length) and (r) is the radius of the circle. We leave out the calculations where we should know exactly the radius of rotation. Because we have in succession two rotation circles (one is longitudinal and

the other is sagittal), that is why the radius cannot be established correctly. We know with approximation the point from where the rotation starts; however, the end of rotation will end approximately before the defender lands down on the mat.

Now, let us see the energy spent by the defender: Let us say hypothetically the defender falls straight down; then, *PE* at the top (before to be thrown) = $m \cdot g \cdot h$. Then *KE* at the mat (when the opponent has been thrown) = $1/2m \cdot v^2$ at the bottom. Or more correctly $KE_{rot} = 1/2\ I \cdot \omega^2$.

If we consider for verification the impulse at the time of landing, then the time of delivery is longer than a karate execution, such as a punch or a kick. For this reason, the force delivered must be decisive for a strong impact delivery (see Figure 10.5a–d).

10.1.9 Conclusion about the Judo Throwing Techniques (*Nage-waza*)

As stated previously, the arms play a primary role in the successful throwing of the opponent; the next role is to keep your and the opponent's equilibrium, during stepping/walking and during the throwing movements. It does not matter which technique will be used; it is decisive for the correct execution of a technique that the opponent to be guided/lifted as high as possible. The higher the opponent is lifted, the more the technique execution will be successful. Why is this? Here are several facts about the height of the opponent:

1. The higher the opponent, the more likely the falling technique will be scored as a "full point" (*Ippon*). The description about the point system will be explained later on.
2. The lower the opponent during his lift/flying, the shorter the time will be for the attacker for turning/twisting with the arms, which cannot be done efficiently. To understand the second point, here is the explanation about the time table of the opponent who is thrown from the end of the "preparation" (*Tsukuri*) to the end of the "throw" (*Kake*): the shorter the time for the fly, the lower will be the opponent; it is then not possible to turn/throw/maneuver the opponent correctly. In this case, if the opponent falls, for example, on his side, the attacker will get less point.

Points according system of throwing techniques in judo:

- *Ippon* (full point or 10 auxiliary points). The judoka who obtains Ippon wins immediately. The Ippon is given when the opponent

who has been thrown falls on his back (on both his scapulas with a full force).

- *Wazaari* (7 auxiliary points). The judoka falls only on one side of his back (scapula) with sufficient force.
- *Yuko* (5 auxiliary points). The judoka falls on his lower back with sufficient force and possibly on his side of the body.
- *Koka* (3 auxiliary points). The judoka falls down somehow and remains for a short time on his back.

The correct body displacement (close to opponent), body turning (*Tai-sabaki*), is a primary factor in case of using hip or shoulder throws techniques. The judoka must be a well-proportioned athlete with all the muscles of the body equally developed. To give some examples:

The neck muscles are important to be strong to resist against choking techniques. The upper body muscles (arms, shoulders, pectoral, and back muscles) are the most important in hand and arm movements (off-balancing, throwing). The thigh, leg, and foot muscles are important for squatting (hip techniques) and sweeping techniques.

Note: It is important to mention that out of the *Go-kyo* system of 40 throwing techniques, only 6 can be considered linear executions, but in these executions, we must consider only a *point mass* from the attacked leg and they are: forward foot sweep (*De-ashi-barai*), large inner reap (*O-uchi-gari*), small outer reap (*Ko-soto-gari*), small outer hook (*Ko-soto-gake*), and small inner hook (*Ko-uchi gake*). Finally, there is another technique named scooping throw (*Sukui-nage*). In this technique, the attacker execution is linear, but the defender's motion is rotational.

10.2 JUJUTSU AND SAMBO: THROWING (*NAGE*) AND TAKE-DOWN TECHNIQUES (*HIKI-OTOSHI-WAZA*)

Sambo throwing technique.

10.2.1 Similarities and Differences between Judo, Jujutsu, and Sambo

The author will not describe the history of these three martial arts here. However, it is important to know that jujutsu is considered the mother of judo and sambo. In sport judo, there are no strikes and kicks allowed. In jujutsu, the techniques are the same as in judo, but strikes and kicks are allowed.

The author will describe the modern jujutsu, where the participants can wear the "outfit" (*Judogi/Kimono*) or they can practice without the *Judogi*. The author will take the initiative and will use the word "Modern Jujutsu," which is also called "Brazilian Jujutsu." The founder of the Brazilian Jujutsu, Mr Helio Gracie, had the idea that jujutsu can be practiced like a sport. Before him, the jujutsu had been practiced only in jujutsu gymnasiums (*Dojo-s*).

Mr Helio Gracie introduced or better said reintroduced attacks against the opponent's legs for immobilizations, which has been forbidden in judo competitions. Jujutsu is not as spectacular as judo because Brazilian

(fighting) Jujutsu athlete initiates mostly take-down techniques by attacking the opponent leg(s) with the arms and does not emphasize the throwing like judo does.

Sambo is Russian Judo and it is the Russian self-defense system practiced by the Russian army, police, and special forces. It is spectacular, probably like judo. It has the same arsenal of throwing as judo has, in addition to throwing the opponent using "free Western wrestling techniques" such as attacking the opponent's leg by hooking with leg.

In the ground techniques, strangulation is prohibited. They maintained from judo the leg and arm bar or key techniques and pinning techniques. The anatomophysiological and psychological basis to become a champion is similar to judo characteristics.

It is important to explain the Ultimate Fighting Championships (UFC). Under the UFC, kicking, punching, striking, holding, choking and almost any kind of action to subdue the opponent are allowed. This kind of fighting includes the mixed martial arts (MMA) fight too.

Here, the participants fight preferably with no "specific outfit" (*Keikogi.*) Some participants prefer jujutsu type of actions; others prefer karate type of actions. For those who prefer jujutsu type of techniques, the victory could come faster than with the karate type of techniques.

The word jujutsu can be written as Ju-jutsu, Ju-jitsu, or Jiu-jitsu. The correct terminology according to the Kodokan Judo is "Jujutsu."

10.2.2 Objectives

After reading this section, you will be able to understand and do the following:

- Describe the major biomechanical characteristics.
- Describe the major take-down technical characteristics.
- Explain the different kinematic chains and their actions.
- Explain if the opponent's body can involuntarily help in the success of the attacker.
- Explain the different leverages used. Explain the difference (advantage or disadvantage) over the arm/leg *bars* and arm/leg *keys*.
- Compare the static and dynamic positions and which one should overcome the other and in what situation.

10.2.3 Biomechanical Principles in Jujutsu and Sambo

1. The jujutsuka who prefers throwing will stand tall. The one who prefers take-down by the arms against the opponent's leg has a lower standing position and leans his upper body forward.

2. The calculation of forces (impulse, collision), energy, work, and power is mostly done under the linear motion of kinetics for the attacker and the defender alike. The exception case is when the opponent is thrown.

3. In jujutsu competitions (Brazilian Jujutsu rules), the attacker does not receive points for throwing. Points are obtained when the opponent gives up by tapping the mats.

4. Each participant looks for the best leverage positions. For this they use any part of the *Kimono* or the pants (*Zubbon*). Almost all the leverage applied happens on the ground.

5. Recall that in sambo there are identical techniques to be used as in judo and the sambo practitioner gets points for throwing. That is why the participants stand taller than in jujutsu (with Gracie-type and/or MMA-type Jujutsu).

10.2.4 Biomechanical Analysis of the Techniques

Because of the nonuniformity of jujutsu and sambo, the analysis will be difficult. The author will explain all the time each technique under different rules. The grabbing (*Kumi-kata*) of the practice uniform (*Keikogi*) is important; however, it is not so important like in judo. The reason for this is that the fighter is preoccupied not to obtain points by throwing but to get the opponent down and to put into submission or knock him out under the UFC rules.

If the match is held with *Keikogi* and one or both of the participants assured the grabbing (*Kumi-kata*), then most of the time the other person tries to break down the grip of the opponent. Holding in continue the opponent's *Keikogi* the take down the opponent the technique mostly will be a hook with the attacker's leg against the defender's leg.

If the match is held without *Keikogi*, both athletes try the take-down techniques against leg(s). In case when one of the athlete prefers throwing, then the technique will most probably be a hip technique where it is not necessary to have the *Kumi-kata*.

If the contestants wear *Keikogi,* then the *Kuzushi* and *Tsukuri* virtually are the same as in judo contests. If the contestants wear no outfits (*Keikogi*), then there is almost no *Kuzushi* and no *Tsukuri* can be observed. It is possible to say that when the contestants are clenched grabbing each other's arms/legs or any body parts, then there is a short time of *Kuzushi* and *Tsukuri* until one of the contestant falls down.

10.2.4.1 Take-Down

Talking about take-down, it is obvious that any kind of throwing similar to the judo technique represents a take-down, which is used in jujutsu or sambo. However, in this chapter, the author will describe take-down when the attacker grabs the opponent's arm or leg and then leads/guides down on the ground. It is important to mention that in self-defense, when you want to use jujutsu techniques to take down your opponent, it is advisable to hit him first to distract him about the technique that you will use after that hit.

10.2.5 Arm Bar (*Ude-gatame*) as Arrest Technique

In this technique, the one who executes the arm bar technique is the attacker, the one who tries to take down his opponent. The attacker is represented on the right side of Figure 10.6a–e. The two participants face each other in standing position. The opponent (defender) stays with his left leg forward position. The attacker stays in a similar position, but with his right leg in front of his opponent (Figure 10.6a).

The attacker slides forward with his right leg and outside of the opponent's left leg. At the same time he grabs the defender's left arm at the wrist with his left palm (which is held at the chest level). Also at the same time of grabbing of the opponent's left wrist, the attacker executes a right knife hand [pushing] strike (*Shuto-tsuki*) at the defender's neck (carotid area) (see Figure 10.6b).

The attacker now will move his right leg in front of the defender. With his right palm pushes the opponent face then his arm will surrounds the defender's left arm in front of his chest area (Figure 10.6c and 10.6d).

Note: The arrows indicates the actions of the right arm of the attacker. The arrow in Figure 10.6e indicates the action of the armpit. In Figure 10.6f, the arrow indicates the shoulder action.

After surrounding the opponent's left arm, the attacker grabs his own left arm at the wrist level and applies an arm key (Figure 10.6d). At this time, the

FIGURE 10.6

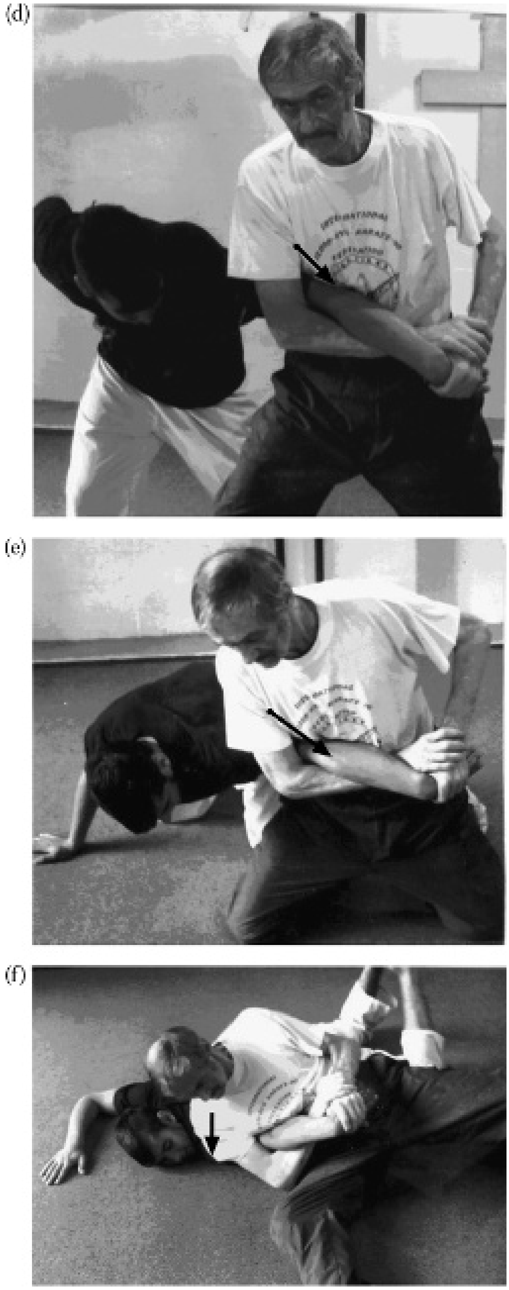


FIGURE 10.6 (Continued.)

attacker, using his body weight, deliberately falls down on his knees, pulling down the opponent (Figure 10.6e). The attacker continues to pull the opponent's left arm with both arms and guides the arm under his armpit (Figure 10.6f). The armpit arm lock (*Waki-gatame*) uses an "arm bar" (*Ude-gatame*) technique where the attacker pulls up the opponent's arm and presses down with his armpit close to opponent's elbow, causing pain to the defender, who will give up by tap-out (Figure 10.6a–f).

How can the opponent defend against the attacker? Obviously, the defender can step back, deflect the attacker's hit, and pull his attacked arm back and other modalities. The author will explain the modality of defense when the attacker has already grabbed the defender's arm with his both hands.

At this time, the defender must do two actions at the same time: the defender will step forward and to the left with his right leg to face the attacker and at the same time bend his left arm. By bending his left arm, he releases the holding arm bar grip and he can counterattack.

When the attacker sees and feels that he will lose control against the defender's arm, he must find another additional base to control the first position for pain, which is the elbow. In this case, the attacker must twist the defender's wrist counterclockwise and curl up. The defender will give up because he has two points where he experiences pain.

In jujutsu, perhaps the most important physical attribute is the leverage. If you know the correct leverage, you are the winner. Just for the sake of a better general knowledge of the reader, the author who is also the founder of the so-called "Sticky Hands Combat Jujutsu" style will describe nine *basic principles* in defense and attack.

1. Balance/stability—This principle deals mostly with the CoG and the BoS.

2. Continuous motion—This principle should explain that your motion from the beginning to the end must flow continuously without interruption.

3. Contact/firmness—Applying pressure or any contact must be extremely firm.

4. Fluidity—During your contact, if it is necessary to change the technique, you must find the way to go from one technique to another with fluid uninterrupted motion.

5. Speed/mobility—Speaks for itself.

6. Striking (*Atemi*) and pressure of vital points (*Kyusho*)—Before applying any technique, use a blow directed at vital areas or use pressure against vital points.
7. Leverage/fulcrum—It is vital to know when you press the fulcrum and when you must lift up the lever. You must create the smallest base to create pain in your opponent.
8. Control/sliding—When you control your opponent with a particular technique, your fingers must slide down or up on your opponent's arm until final immobilization.
9. Additional base—Create another base to inflict pain and to control the first position.

10.2.5.1 Observation of Physical Properties of the Arm Bar Technique

Recall that the lever is one of the most important biomechanical components of the body. In this technique, the obvious lever is the defender's left arm (upper and forearm). The opponent's arm forms an open kinematic chain. Every joint can be considered as a fulcrum. In our case, the shoulder is considered as the fulcrum only if the opponent's total arm is extended. The attacker must lift up the defender's arm, which in our case, represents the effort arm (EA) that covers the entire length of the arm until the shoulder. The resistance arm (RA) is the weight of the attacker (see Figure 10.6e, the arrow indicates the attacker's chest), where his effort is directed downward at the elbow or at a small distance from the elbow toward the shoulder (approximately 1/4th distance). This is a second class lever.

The reader can ask how it works if we consider the elbow as the fulcrum. The answer is the same as in the previous case considering the shoulder. The little difference will be that the weight of the attacker (the attacker's chest) should be held exactly on the elbow (fulcrum). The RA will be "0" or will be very short (see Figure 10.6c). If the weight of the attacker is a little bit farther from the elbow, as 1/4th the distance toward the shoulder, then the elbow can be bent and the defender can escape.

The FA will be the distance between the elbow and the wrist of the arm. The effort itself will be directed by the attacker, lifting the defender's arm up (this is not "armpit arm hold" (*Waki-gatame*), but "arm bar" (*Ude-gatame*)). We can mention the momentum of the attacker, which will be small because of the short time of velocity. The work of the attacker will be simply calculated with the equation Work (W) = $F \cdot s$ (*displacement*). Here,

the work is negative because the attacker drops his knees on the floor. $KE = 1/2\, m \cdot v^2$. As an example, the mass of the jujutsuka is 70 kg, and the average velocity is 1.2 s. Then, $KE = (1/2)(70\ \text{kg})(1.2\ \text{s})^2 = 50.4$ J. For calculation of power, we use the equation of power (P) = W/t or $P = F\Delta d/\Delta t$.

10.2.6 Leg Locks (*Ashi-garami*) as Arrest Technique

Both combatants face each other. The defender (D) defending against a roundhouse kick that is on the right side of the figures has two options to take down his opponent: (a) when the opponent attacks with a kick and (b) when (D) picks up (A's) left leg by squatting down. We will analyze option (a). A short note is required to explain the roles of the attacker and the defender.

In our case, the combatant who kicks is the attacker (A) at the time of the kick. Then, because the defender (D) blocks the kick, the roles will change and the defender will turn to be an attacker. Basically, after blocking the kick, (D) will continue to take down his attacker (A). For a better understanding of the roles, the author gives for each person a letter (A) and (D). Let us analyze the entire attack, block, and counterattack (Figure 10.7a–f).

The attacker (A) executes a roundhouse kick with his left leg against the defender's (D) face (Figure 10.7a). The defender blocks the kick with his right forearm, then turns his right forearm counterclockwise grabbing the leg into his elbow pit. The defender then turns the grabbed leg counterclockwise by pushing the attacker's thigh with his left forearm. Almost simultaneously he strikes with his left elbow (or with the left knife hand) at (A's) thigh approximately in the middle and lateral part of the iliotibial tract (Figure 10.7b).

Now the defender (D) becomes the attacker. To eliminate any confusion, (D) will remain the defender who counterattacks. He pulls (A) a little backwards and pushes his thigh down (Figure 10.7c). When (A) is down on his stomach, (D) steps with his right foot over (A's) left thigh close to the popliteal space. Also, (D) will block (A's) left calf and grabs his foot with the right arm (Figure 10.7d).

Fighter (D) is on his left knee and pushes forward (A's) left calf with his body (Figure 10.7e) and can also turn/twist (A's) foot to the right or to the left (Figure 10.7f) to inflict pain on (A) who will give up by tapping out on the floor.

Note: The pain will be greater when the defender's foot is twisted outside (lateral rotation), instead of inside (medial rotation). During rotation, the calf and the foot should be kept at a 90° angle.

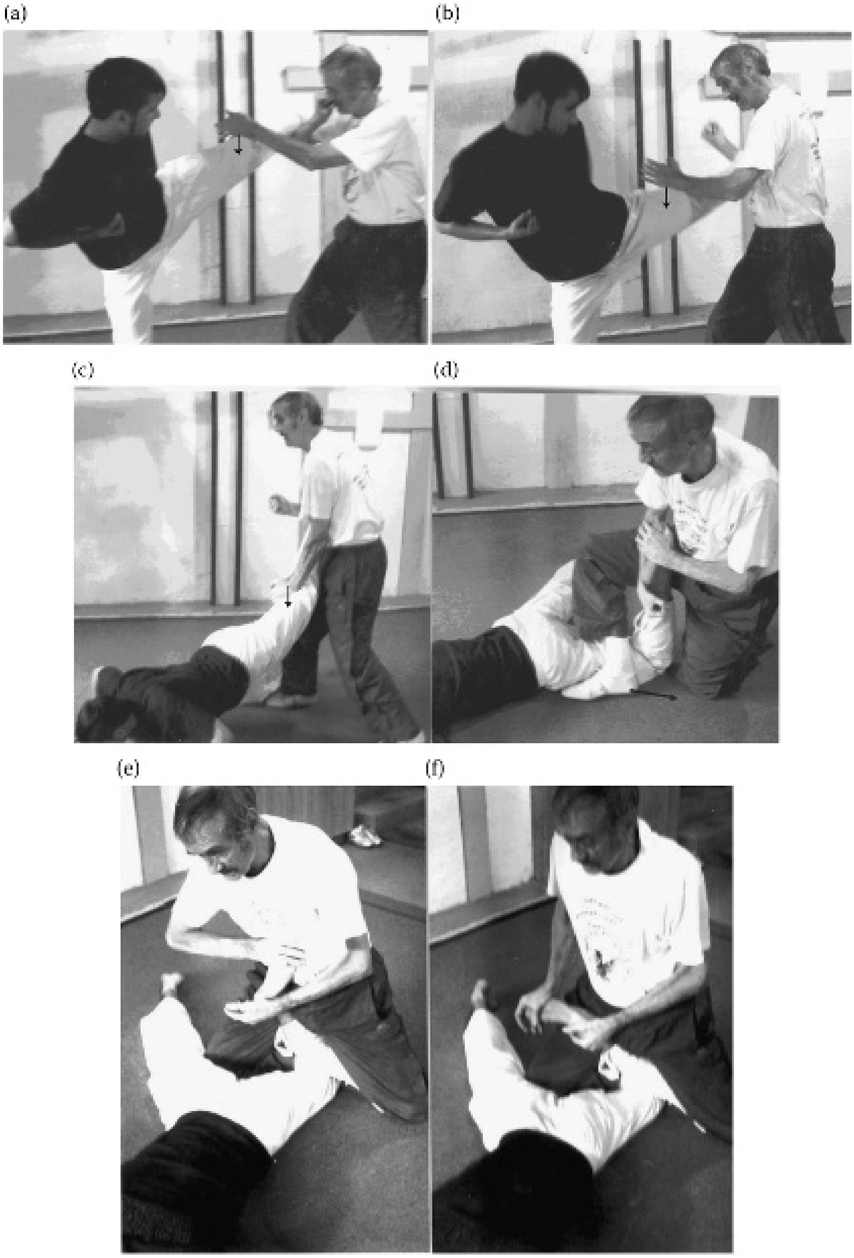


FIGURE 10.7 (a–d) The arrows show the action of the body segments and their direction.

10.2.6.1 Observation of Physical Properties of the Leg Locks Technique

As a general observation, attacking an arm with jujutsu techniques (twisting, pressing, bending, etc.) is easier compared with attacking a leg. Because the leg is approximately 2 times stronger than the arm it is advisable to attack mostly the arm.

Directly attacking a leg can also be dangerous because in order to get closer or pick up the opponent's leg, usually the attacker must incline his upper body forward to grab the opponent's leg. At this time of forward and downward inclination, the attacker is in danger to be kicked with the knee of the opponent or struck on his back.

For these reasons, the attacker must execute feints in order to pick up the opponent's leg(s). When the opponent's leg is picked up, he is obviously off-balanced; however, the attacker has his problem too because the weight of the defender's leg and his upper body is shifted far from the attacker's holding arm(s). Recall that in our case, the person who defends against the kick and counterattacks becomes an attacker, but we will continue to call him the defender (D).

Figure 10.7b demonstrates this. (D) applies a lever against (A). The axis of rotation is at the coxofemoral joint. Until the attacker's leg is extended, this lever is considered as a second class lever where the effort arm (EA) is considered the entire leg. The effort is directed by the defender (D) who lifts the opponent's leg upwards at the foot. The RA is considered to be the mass of the arm/shoulder of (D) and the gravity too.

The reader can ask why (D) lifts up the leg of the opponent, when he should push it down. By lifting up the leg (for a very short time), (A) will lose his balance. Also, if (D) pushes down immediately after grabbing the opponent's (A) leg, he can escape easily.

Work done $W = F \cdot s$. The work is considered when (D) starts to push (A's) leg completely down. The work on (A's) leg is considered as negative because the thigh muscle is stretched during an eccentric movement, also opposing gravity. The defender's (D) potential energy (*PE*) will turn into kinetic energy (*KE*) after he managed to take down his opponent (A). We will use the following equation: $W = \Delta KE = KE_f - KE_i = 1/2mv_f^2 - 1/2mv_i^2$.

10.2.7 Defense against Grabbing

The defender (D) is on the left side of the photos. The attacker (A) on the right side grabs the opponent/defender's lapel of the *kimono* (Figure 10.8a). The defender in this technique will use *pressure point* (*Kyusho*) technique in order to subdue his attacker. At the moment when (A)

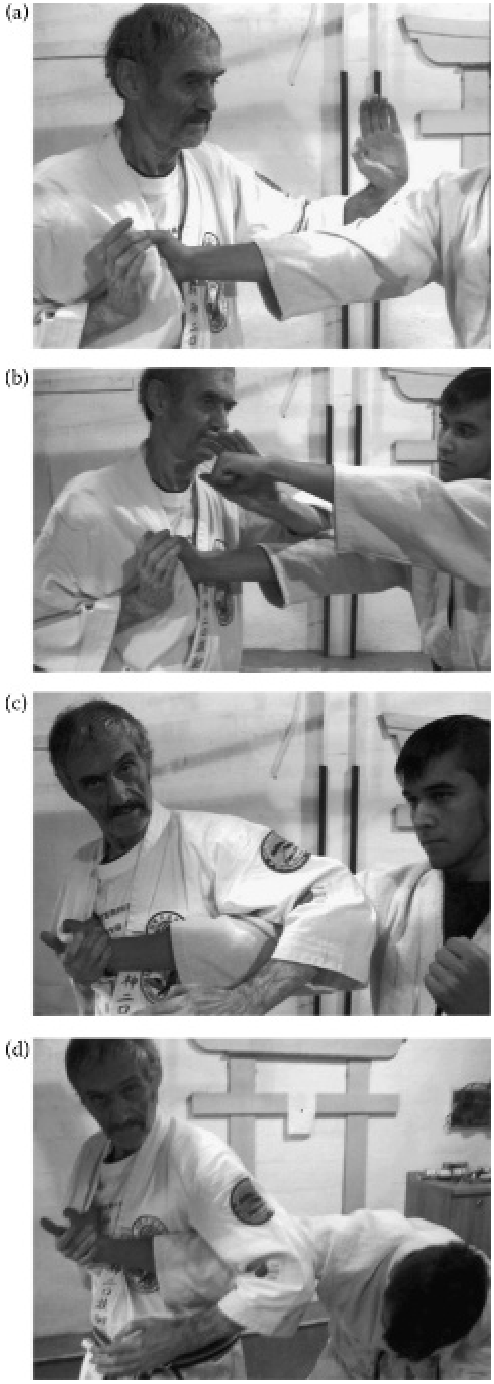


FIGURE 10.8

(e)
(f)


FIGURE 10.8 (Continued.)

grabbed (D's) kimono, the defender will block a punch directed toward him from (A) (Figure 10.8b). After blocking the attack, the defender swings his left arm over (A's) right arm (Figure 10.8c) and simultaneously grabs with his right palm the attacker's palm base (the thenar and hypothenar area).

From this position (Figure 10.8c), the defender has at least three choices to defend himself:

1. Execute with his left arm a back fist strike to the attacker (A's) face
2. To pull toward his chest (A's) arm by extending his elbow

3. To twist (A's) fist forward and at the same time to execute pressure against (A's) elbow (Figure 10.8d)

To disarm the attacker's right hand grip is now up to the defender's technical knowledge. The defender should execute the following hand manipulation:

1. The defender must tightly hold the attacker's right arm close to his chest.
2. The defender grabs the attacker's thumb with his left palm instantly between his thumb and his forefinger, surrounding it to form a claw (Figure 10.8e). The claw squeezes the distal phalanx of the thumb and distal end of the first metacarpal of the thumb. To create even more pain and to be absolutely successful, disarming (A's) hand, the defender can push the distal phalanx of the thumb with his right base of the palm (Figure 10.8f).

The defender squeezes the attacker's thumb hard enough and creates pain, and the attacker gives up and releases his grip. From a released position, the defender has endless possibilities to counter.

10.2.7.1 Observation of Physical Properties of the Defense against Grabbing

In this technique of defense against grabbing (grabbing with one arm), the reader could wonder what kind of physical properties we can talk about. Let us analyze the attacker's physical properties:

The punching arm force comes from the left arm of the attacker (Figure 10.8b). The punching arm should be accelerated to be destructive. We can speak about muscle strength contraction. In our case, the punching muscles of the arm do an eccentric contraction. Using the combination of energy, work, and power, we can easily establish these physical properties.

The work (W) done by the arm $= F \cdot s$, where the s is the displacement. Finding the acceleration of the arm, we will use the formula $a = \mathrm{m/s^2}$ (a = acceleration; m = meter; $\mathrm{s^2}$ = second squared). If we want to calculate the force, then $F = m \cdot a$, and an approximate calculation will be: a punching arm mass is about 4 kg. Then the N of the punching arm is about 39.2 N, if we use the acceleration due to gravity. However, we calculate

by using a linear average acceleration (a) of 0.2 m/s^2. Here, we took only the final velocity, assuming it to have an average acceleration. Then, $(a) = 0.2^2 = 0.04$ m/s^2. The final $F = (4\ \text{kg})(0.04\ \text{m/s}^2) = 0.16$ N. Although the attacker has 70 kg mass, we do not take it into account.

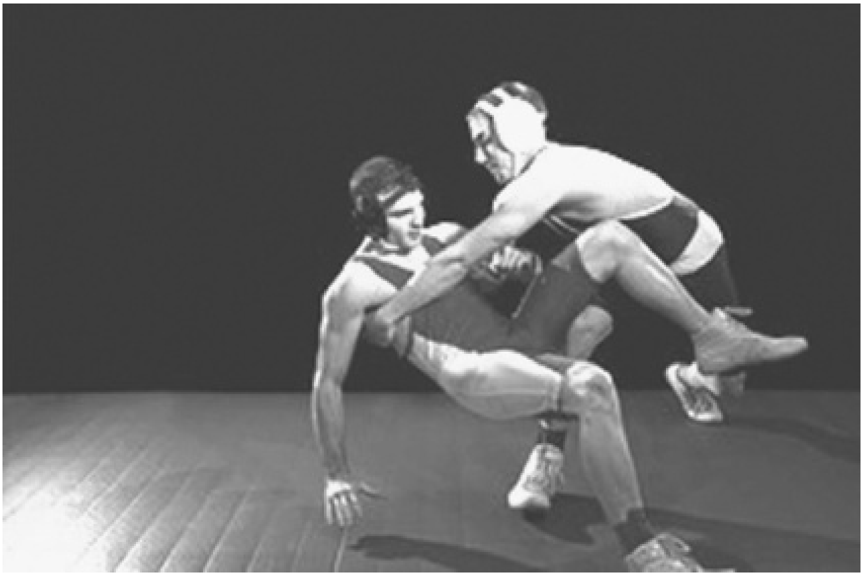
When calculating the punching arm's force, energy, or work, we do not use gravity in our calculation because the punching occurs horizontally to the ground. Let us analyze the defender's physical properties:

The defender, besides blocking the attacker's punches, must liberate himself from the attacker's grabbing. The attacker grabs the defender's kimono (Figure 10.8a) and creates a chance for him to throw the defender with a shoulder throw (*Eri-seoi-nage*) technique or initiate a leg sweeping or hooking technique or any other possibility to continue his attack.

The defender's chance to defend himself is by counterpunching the attacker, and then to apply a squeezing technique on the attacker's fingers. At this time, the lever is a mechanical property of the muscle. The lever is applicable to the attacker's right arm. Once the defender surrounds the attacker's arm (Figure 10.8c), he can maneuver the attacker's arm. The applicable lever will be the third class lever created by the attacker's arm. The fulcrum is at the elbow. The effort arm will be between the fulcrum and 1/3 distance on the forearm, where the side (ribs) of the defender will push forward. The end of the arm with the fist will represent the resistance arm.

This interpretation can also be reversed; it depends on how strongly the push against the defender's rib is or how strongly the defender will pull the fist of the attacker (Figure 10.8d) toward him. Another interpretation can be made up if the attacker's shoulder represents the fulcrum; then in this case, the total arm length will be taken into consideration. In this case, the shoulder is the fulcrum, the effort arm is the total length of the arm, and the resistance arm is from the fulcrum until 1/2 distances on the forearm. It can be considered as a second class lever.

10.3 AMATEUR WRESTLING: TAKE-DOWN AND THROWING TECHNIQUES



Greco-Roman wrestling (take-down).

10.3.1 Historical Background

It is well known that the great civilization of the Sumerians, with flourishing arts and philosophy at approximately 3600–3700 years ago, practiced a form of hand-to-hand fighting similar to that of our modern time boxing and wrestling scenes. Very similar depictions are found on the base reliefs of Egyptian tombs that are 3000 years old.

Before the first Olympic Games (776 BC), there was an event called Pankration. This was a form of unarmed combat and later it developed into two modern sports of wrestling and boxing. The Greek civilization furthermore developed and organized wrestling and boxing contests between Athena and Sparta. Free Style and Greco-Roman wrestling are great sports. The sport of wrestling is practiced by more people and is more popular than any kind of martial arts.

10.3.2 Similarities and Differences between Judo, Jujutsu, Sambo, and Amateur Wrestling

It is easy to understand the similarities between these fighting arts. They all pursue a throwing or take-down technique to gain point(s) or to subdue the

opponent on the ground. During a take-down of an opponent, the attacker always gains psychological advantage. By reading about judo, jujutsu, and sambo throwing techniques, the reader had the chance to see the similarities as well. However, the differences are more evident and prevailing.

The differences dealing with throwing or take-down techniques are evident by the way they are executed. Judo throwing or takedown is executed mostly with a motion that requires total body coordination and the most important is the arms/hands guiding movements.

Jujutsu and sambo throwing or take-down techniques are executed similarly to judo but can also be done only with the legs guiding movements. Amateur wrestling (Greco-Roman style) throwing or take-down is executed exclusively with the arms. Any leg maneuver is totally prohibited. Throwing is many times spectacular with the attacker's full muscular effort, especially when it is executed by the technique of *suplex*.

Free Style wrestling throwing or take-down techniques are executed with the arms and legs alike. Any kind of combination is allowed; however, there are rules that prohibit different techniques (especially combinations used with arms and legs together) that could jeopardize the wrestler's body integrity. A specification is needed about the words *throwing* and *take-down*.

In wrestling, it would be more proper to use the word take-down because when an attacker executes a throw, the opponent should be released at least from the height of the attacker's abdomen. In wrestling, however, when the attacker executes a throw, he never releases his opponent at the time of throwing. Instead of guiding his opponent, both wrestlers fall on the mat approximately at the same time. It does not mean who will be on the top of the other because that depends on the technique.

10.3.3 Objectives

After reading this section, you will be able to understand and do the following:

- Describe the major biomechanical movement characteristics.
- Explain the different leverages used for different techniques and their mechanical advantage, if any.
- Describe the role of the major neck muscles in the position of the bridge.
- Describe the role of the neck extensor and flexor muscles. Which one is more important in the execution of the "wrestler bridge" technique?

- Explain why in amateur wrestling the break-fall technique is not taught like in judo.
- Describe the major muscular chain in the leg and in the upper body, including the arms.
- Explain why the amateur Free Style and especially the Greco-Roman wrestler's legs are more slender than the legs of an Olympic weightlifter.

10.3.4 Biomechanical Principles in Amateur Wrestling

1. In Greco-Roman style of wrestling, both wrestlers stand taller than in Free Style wrestling. The wrestlers do not have to defend their legs from an attack. In both styles of wrestling, however, both wrestlers incline their upper body a little bit forward.

2. In Free Style wrestling, both wrestlers stand with their upper body bent forward. In both styles, once the wrestlers have clenched, there is a lot of pushing going on and a lot of fighting to get the best holding position.

3. When a wrestler grabs his opponent, for example, (*bear hug*) on the upper part of the torso, and initiates a throw, for example, a suplex or any other technique of throwing such as shoulder throw, the thrower basically throws himself (sacrifice) to the ground for two reasons: (1) The opponent must be pinned as soon as he lands on the mat, so, the thrower and the defender is basically one person and they will land together. Compared with a judo throwing technique, the thrower could remain in standing position. (2) By landing together, the defender could have an easier landing not as hard as in judo throwing.

4. The attacker who initiates a throwing or take-down technique has a longer time of contact with his opponent compared with judo or jujutsu.

5. To maintain equilibrium in wrestling is more difficult than in judo. To maintain the equilibrium in judo, the outfit (*Judogi*) helps the participant because of the grip on the jacket (*kimono*). By having the grip on the *kimono*, both participants can handle their own balance with an extra leverage that is offered by the opponent's jacket.

To maintain equilibrium, there are several important factors that intervene during wrestling for both wrestlers. They are CoG, CoM, BoS, friction, weight of the wrestler, inertia, and interactive forces of the so-called *permanent contact/link* of the two wrestlers and also many of the different physical quantities that will be discussed under the technical analysis of the techniques.

During throwing or take-down executions the attacker must lose his equilibrium in order to fall down with the defender in order to execute the final fixing position on the mat. This is in contrast to judo where it is not necessary to fall down with the defender. The attacker simply throws the opponent and will then get down in order to fix the opponent if it is necessary. Recall that in judo, a correctly executed throwing technique is a victory.

The CoG and CoM are permanently changed by both wrestlers. It is important to know that when the execution time arrives, the attacker must liberate from the defender's pulling or pushing action. In this way, the attacker can finalize his technique with full force.

In wrestling it is difficult to grab and hold the opponent's arm, leg, or any part of the body because of the perspiration and the larger size of the grabbing part in comparison with judo.

6. Throwing execution will take more time in wrestling than in judo or jujutsu.

7. Maintaining the CoG is also very important for the equilibrium. A wrestler can direct more easily his CoG by using the opponent mass or simply his mass. For example, in Figure 10.9, wrestler (A) has an excellent balance even if he is inclining against the opponent (D) (defender). If opponent "D" moves one of his leg forward, then

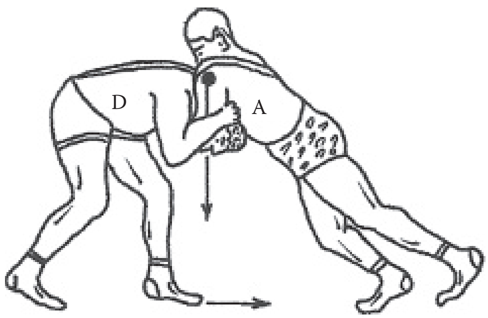


FIGURE 10.9 Wrestler having permanent contact/link.

he will gain better balance and wrestler (A) loses balance because his CoG will move further upward from his original location of the CoM. Even by his moved position, wrestler (A) still has a pretty good equilibrium because he has contact with his opponent and he can use (push or pull) (D's) body to maintain his balance.

By having two wrestlers in *permanent contact/link* position (described in Summary of Part IV), the BoS is larger. The *permanent contact/link* makes the kinematic muscular chain as one.

In Figure 10.9, the large black dot on the attackers A represents the left shoulder and the direction of the arrow from the shoulder shows the pushing force direction of the attacker (A), which acts downward on the defender's neck. Here is another force (there is no arrow to show the direction of the force couple, which is the defender's neck force that directs parallel upwards with the attacker's pushing force).

In Figure 10.9, the force couple can be interpreted as just two opposing forces if there is no axis of rotation and the forces are not equal. The attacker pushes the defender's neck down using his armpit. In this case, the rotational axis, which is mostly imaginary, could be the middle of the attacker's arm. Obviously, it is not easy to establish the axis of rotation because the wrestlers are permanently moving and the axis obviously moves too.

Recall that the force couple acts simultaneously on the opposite sides of an axis of rotation. Usually the forces are equal in magnitude. The magnitude of the force couple is the sum of each force and its moment arm. In the example (Figure 10.9), the two forces presupposed are equal. At the moment when one of the forces has a larger magnitude, the force couple is not in effect anymore and then the larger force will dominate all the execution and its direction.

Figure 10.10 shows a more realistic example of a force couple. The attacker on the right side of the figure embraces (D)'s both legs at the popliteal space. The attacker pulls the defender's legs toward him and at the same time pushes the defender's thighs with his shoulders (upper portions) where the flexor muscles are *iliacus, psoas, pectineus* and where the adductor muscles are which are also flexor assistants, such as *adductor brevis* and *longus*. From Figure 10.10 the direction of both forces can be seen clearly.

The axis to be established again is somewhere in the middle of the thigh. If the attacker would pull the defender's leg at the ankle level, the take-down will be very difficult because the attack probably will not succeed by the defender bending his knee (flexed position).

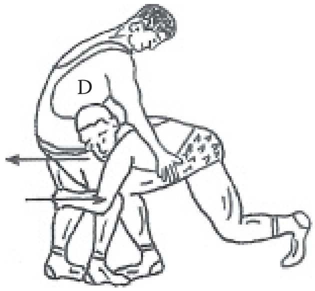


FIGURE 10.10

As a reminder, in almost any force couple, the finalization will turn into a twisting action of the attacker against the limb(s) of the defender. Any force couple with absolutely equal forces and equal distances from the (imaginary or real) axis cannot work forever in sports. In order to be a winning force of the couple, one of the forces must turn into a twisting execution. If two forces are equal in magnitude and have the same distance of the moment arms, then the rotation could occur forever; an example is the pedals of a bicycle.

10.3.5 Biomechanical Analysis of the Techniques

Just like in judo, jujutsu, sambo, and amateur wrestling, there are basic and fighting positions. The wrestling positions are similar to sambo and Brazilian Jujutsu. The wrestler's weight is distributed pretty much evenly just like in judo, especially when the wrestler does not intend to attack. If the wrestler initiates an attack by grabbing the upper part of the opponent's body, then the forward leg supports a little bit more weight.

Both wrestlers have all the time one leg in front of the other leg. Very seldom are both feet parallel.

The attacker's contact with the ground is mostly with the balls of his foot. His body is inclined forward about 30–35° from the vertical. His body almost completely lost its balance. The defender has a great chance to pull and twist his opponent's body when he releases his grabbing from the attacker.

During wrestling, the time for active fighting could be divided as 50% for standing wrestling of tackling (pushing, pulling, twisting, and entering for a take-down or throwing position). The other 50% active fighting is given for the ground techniques, which includes standing on knees, moving around the opponent, and being or holding down mostly in the bridge position.

The bridge position requires enormous muscular endurance and also a good adaptability to aerobic and anaerobic activity. For the attacker, who

tries to push the defender into total submission, he has to make a considerable effort.

The wrestler who is in bridge position must hold his head in an extension position for quite a long time. The head with the neck can have an extension of about 45–55°. Flexion of the head with the neck reaches only about 30–35° angle from the vertical position. This requires an extraordinary muscular and physiological effort. The attacker pushes down the defender's shoulders hard. There are 16 neck muscles categorized by anatomists; however, only eight are directly involved in holding the position of the bridge, plus some muscles from the upper part of the body. These muscles are anterior vertebral muscles: *longus colli, longus capitis* (both muscles flex the head), and *rectus capitis anterior* (turns and inclines the head). The muscle of the *scalene* (also flexes the head) and *sternocleidomastoideus* (the strongest of the neck muscle flexes and rotates the neck) also elevates the thoracic cavity during inspiration.

Some muscles from the trunk also have action on the neck and they are *longissimus capitis* (bilaterally extends the spine and lateral flex the head), *splenius capitis* (rotates and extends the spine), *splenius cervicis* (rotates and flexes the neck), and *levator scapulae* (elevates the scapula, helps the lateral inclination of the neck). One of the strongest muscles is the *trapezius* that rotates, elevates, and adducts the scapula. Being in an extended position during the bridging, it should be obvious that the muscles that support extension should be stronger than those that support the flexing position of the neck. However, the flexor muscles (which are stronger than the extensor muscles) have a very important role to sustain the long holding position of the bridge.

10.3.5.1 Take-Down Techniques and Equilibrium

For any action, the wrestler must have a permanent care about his equilibrium. Many times when an attacker pushes his opponent, he is not in a balanced position. His CoG and BoS must create an optional position from where he can act relatively easily. We know that when all parts of a body are at rest or moving with a constant velocity, the body is in the state of equilibrium.

The resultant of the component forces in any direction must be zero. In order to maintain the desirable equilibrium in attacks as well as in defense as has been mentioned before, the CoG, BoS, friction, mass, inertia of the wrestler, and the strength of the wrestler play a decisive role for victory. The defender's BoS, his strength, and so on also intervene for the maintenance of the equilibrium of the attacker.

Recall that at the beginning of this chapter it was mentioned that it is difficult to describe or analyze biomechanically the majority of martial arts. The majority of individual sports describe mostly one aspect, which can be linear or angular, but there mostly only one athlete is involved. In wrestling, there are always two athletes involved and most of the time when the action/technique is about to be started or is already started, the two athletes make a *biomechanics system* (*fighter–fighter*).

As we know, perhaps this system can be considered as one, but in reality it is not one because both fighters act and think independently. Most importantly, the fighter's action happens in a fraction of a second. Later on, we will analyze the biomechanics of ground techniques where the physical properties will be analyzed much more easily.

For a successful off-balancing of an opponent, there are several procedures:

- Pull, push, or twist the opponent arms, legs, and the head in a certain way
- Hooking of the opponent's arm(s) or leg(s)
- Ducking during an opponent attack or side stepping with grabbing of the opponent's arm
- Use of the opponent's reaction by your action of pull, push, hook, and so on
- Creation of force couple that works in contrary sense, for example, the attacker hooking and lifting or pulling toward him the opponent's leg, which is in one direction, and he pushes back the opponent's chest in the opposite direction. The pushing must also be downward to counterbalance the lifting action of the opponent's leg.
- Raising your CoG when attacking the opponent in case of lifting your opponent. If your CoG is elevated, any attack action can be executed more easily. Lower your CoG and then you will be in a better defensive position.

10.3.5.2 First Take-Down Technique (Arm Pull, Head Wrap with Knee Drop)

This technique is called *Soto-maki-komi* in Japanese. This technique can be used by Greco-Roman and Free Style wrestlers. The wrestlers face each other; both are with their right leg in front (Figure 10.11a). The attacker

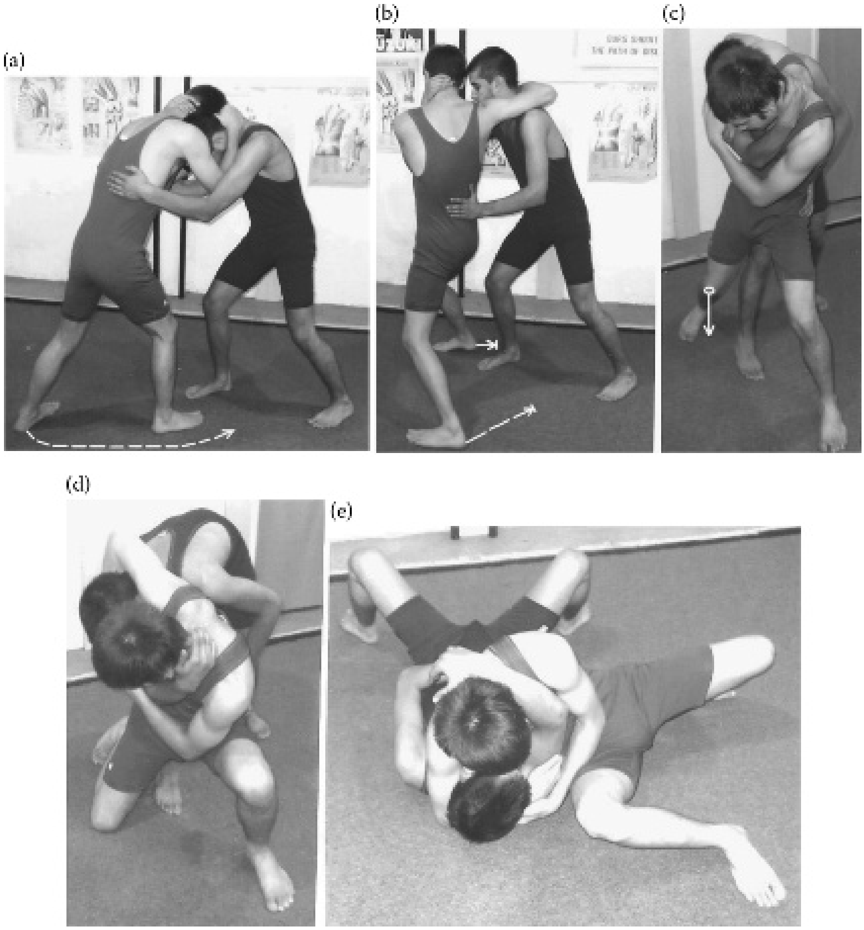


FIGURE 10.11

wrestler (A) on the left side (light-colored singlet) of Figure 10.11a and 10.11b grabs the defender's (D) right arm above the elbow or a little bit higher with his left hand.

It is recommended that the grab to be at or above the elbow level. At the same time of the arm grabbing, (A) with his right arm will surround (D's) neck. Once (A) is assured a pretty good grip on (D), then (A) will move his left leg in a rotary motion backward toward (D) and moves his right leg outside of the defender's right leg (Figure 10.11a, see arrows). All the grabbing movements and the leg moving must be done at once as soon as possible. (A) must have a firm contact with (D's) chest. The contact should be with the defender's left side of the neck and the trapezius muscle. Having

assured a good position for the attack, (A) will execute a twisting motion to his left with both his arms.

The attacker (A) basically executes a force couple with both his arms (Figure 10.11b) where the attacker pulls with his left arm the opponent's right arm and push the opponent neck's in a rotary fashion toward the left. In Figure 10.11b at the end of the arrowhead, there is a vertical line that indicates the approximate position of the feet after the turning.

The attacker (A) continues his attack by dropping down on his right knee (Figure 10.11c) by using the force of gravity in his favor (Figure 10.11d). By this action, (D) will be down on his right side or completely on his back. From here (A) has the chance to immobilize his opponent (Figure 10.11e).

In this technique, there are different forces that act upon the wrestlers, besides the wrestlers' forces. They are GRF, friction force—static and kinetic (f), gravity (g), and normal force (F_N). Wrestler (A) experiences static friction force at the beginning of pulling against wrestler (D). Once (D) has been pulled forward, (A) experiences a slight kinetic friction force by moving his feet in a rotary fashion. Wrestler (D) experiences for a short time a static friction force but once he loses his balance, his legs will not support the counterforces applied by the wrestler (A).

10.3.5.2.1 Observation of Physical Properties In this technique, we should consider the work that is done by effort and not by load, which is done by gravity (kneeling down and holding the opponent's body weight). The first and obvious physical property is the momentum, which starts as a linear momentum (at the standing position) for a fraction of a second and then continues as a rotational momentum with the attacker's body turning/positioning against the defender's body.

For the rotational momentum (Figure 10.11b and 10.11c), the calculation will be $L = \text{kg} \cdot \text{m}^2/\text{s}$. For "s," we will use the angular velocity (ω) = rad/s. Both wrestlers have a 70 kg body mass. The axis of rotation will be considered as an imaginary vertical axis line between the two wrestlers' heads. From this imaginary axis, the radius (r) can be considered as one of the wrestler's shoulder edge (*acromion process*), which can be 0.23–0.25 m. We will calculate the angular velocity (ω = rad/s) using radians. The wrestler who takes down the defender will turn 180° = 3.14 rad. The (average) constant velocity is 1.02 s. Then (ω) = 3.14/1.02 = 3.07 rad/s. For calculating radians, the approximate rotational distance (angle) can be considered as 180° turning started from the position of Figure 10.11a and finished to Figure 10.11c.

Calculating the horizontal angular momentum, we obtain L = (70 kg)(0.25 m)^2(3.07 rad/s) = 13.32 kg · m^2/s. We can calculate the mechanical energy only for the twisting and pulling movement of the attacker. Work for the attacker—pulling movement of the defender's right arm (W) = $F \cdot s$ (kg · m). Let us say a 70 kg wrestler pulls (D's arm) for a distance of 0.20 m, then W = (70 kg)(0.20 m) = 14 J. Here, (A) has done a concentric movement and is considered a negative work.

The twisting and pulling of the defender's right arm is going together with the attacker's dropping of his body. We ignore the twisting and pulling movement (a very short action) and calculate (A's) body dropping for $KE = 1/2\ m \cdot v^2$. For the velocity, we use an (average) constant velocity of 1.04 s. Now the total result is KE = 1/2(70 kg)(1.04 s)^2 = 37.8 J. We choose the constant velocity because the defender will not fall like a ball. The defender opposes the force of the attacker; that is why he cannot fall with the full acceleration of gravity.

10.3.5.3 Second Take-Down Technique, Grabbing (Body Scoop and Drop)

Attacker (A) is on the left side of Figure 10.12a–c. He is on the top of the defender (D) in Figure 10.12d and 10.12e. The attacker (A) managed to dodge with his shoulders approximately to the level of (D's) lower abdomen and grabs the defender's thigh as can be seen in Figure 10.12a, his left arm introduced inside the defender's right leg (close to popliteal space) and his right arm surrounds (D's) left thigh (Figure 10.12b).

The attacker has two major muscular actions:

- First, the attacker must assure a very high contact with his opponent especially using his right arm.
- Second, during the lifting up of (D's) body, his left arm will execute a left side and upward pull of (D's) right leg (*like a large swing movement*). This movement is the key to pick up his opponent. The upward pull of the right leg must be executed very quickly.

The attacker now has his opponent on his right shoulder (Figure 10.12b). From this elevated position, the attacker could drop down his opponent like in the mixed martial arts (MMA) competitions. However, a wrestler (A) will guide down his opponent by getting down on his left knee (Figure 10.12c). By getting down on his left knee the attacker has a very good chance to fix fast to the ground the defender with his shoulders (Figure 10.12d).

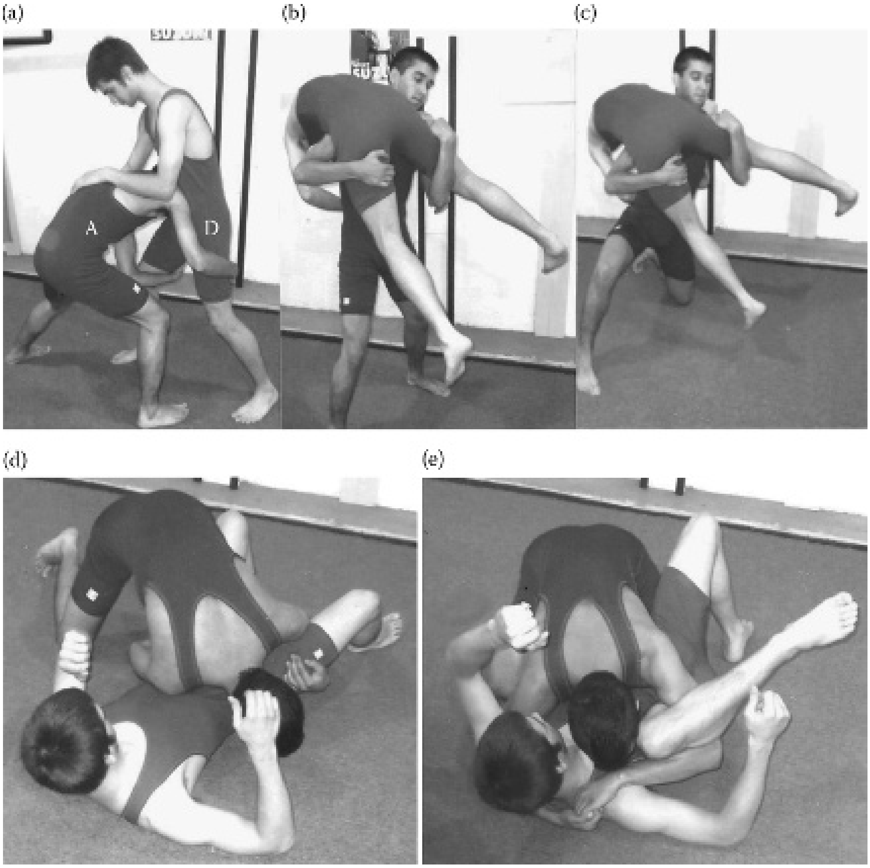


FIGURE 10.12

Figure 10.12d shows that the attacker still has the arms grabbing positions on the defender's body. From these arms positions, the attacker simply slides his left arm into the defender's right leg popliteal space and pulls the defender's leg (knee) close to his chest.

The attacker continues his action to fix his opponent, moves his right arm under the defender's left armpit and pushes forward under the defender's neck, and then the two palms will close to hold down the defender in a secure and fixed position (Figure 10.12e).

10.3.5.3.1 Observation of Physical Properties In this technique, the physical properties are similar to the previous technique; however, the angular momentum is not executed horizontally by the attacker, but it is executed vertically.

The equation for the angular momentum will be similar to the previous technique. There is more *KE* consumed during the take-down of the opponent. Also, the work to be done requires more *KE* because of the higher distance of the defender from where the attacker must take down to the mat.

The velocity of take-down is $v = a \cdot t$, where we use gravity for acceleration. Analyzing Figure 10.12d and 10.12e for leveraging the attacker (A), we can conclude that the defender's right thigh represents the resistance moment arm (RA) where the defender's knee (popliteal space) tries to push away the attacker left arm as much as he can, using also his right calf by flexing it.

The active force moment arm (FA) is the attacker's entire left forearm, including his palm. We cannot be very precise with the direction of the forces. The attacker's right arm will try to pull up the defender's neck to stop any intent to escape. The axis of rotation will be the coxofemoral joint. It is a second class lever (Figure 10.12e). There is another possibility to establish a third class lever; we will not describe this possibility at this time.

In Figure 10.12d, the defender has a chance to minimize or totally exclude the attacker's second class lever, if the defender does not allow the attacker's left arm to slide under the right leg popliteal space. For this reason, the defender should grab the attacker's left wrist for a defense or to push down the attacker's left arm from his thigh (the chance is shown in Figure 10.12d).

10.3.5.4 Third Take-Down Technique (Fireman's Carry)

The Fireman's Carry name came from the fact that the defender's body is on the attacker's back and this position is similar to a fireman who carries an injured person. The defender (D) is on the left side of Figure 10.13a and 10.13b. After securing a good position with a good grip, the right arm is between both legs of the defender (Figure 10.13a). The attacker (A) will kneel down on his left knee and at the same time incline his body laterally left and pull the opponent's right arm toward the left. The pulling arm is not represented in Figure 10.13b.

In Figure 10.13c, the attacker pushes the defender's body over his back toward his left shoulder (like a rollover movement) and additionally uses his right leg pushing force. Figure 10.13d shows that both wrestlers are on the ground. The attacker is on the top of the defender's chest. The attacker still must hold the grabbing position (left arm holds the defender's right arm and the right arm still in contact with the defender's buttock).

The attacker must turn his body over the vertical axis to be on the chest of the defender (Figure 10.13e). The attacker will change his hand's

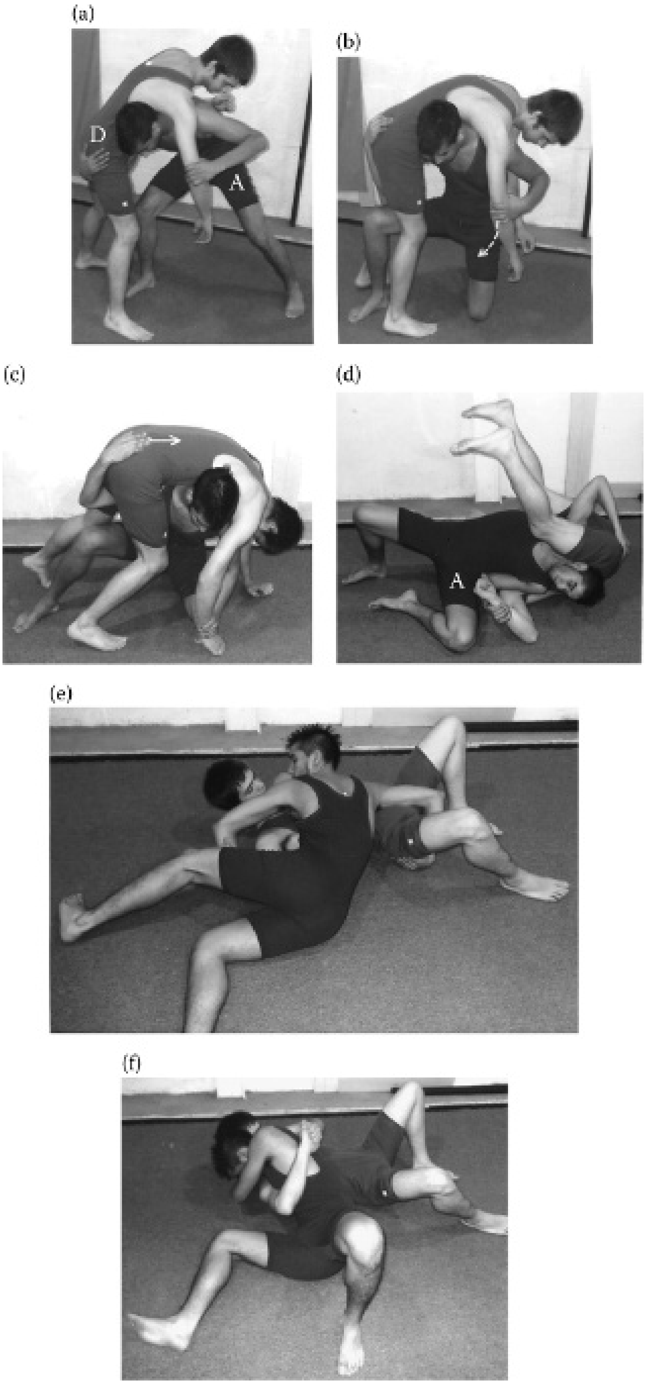


FIGURE 10.13

position and will surround the defender's neck in order to be fixed to the ground (Figure 10.13f).

10.3.5.4.1 Observation of Physical Properties The execution of this technique is simple. The difficulty for the attacker is seen in Figure 10.13d. Here, the defender's legs are in a vertical position. At this position, the attacker must act quickly and turn around on of his vertical axis to get into holding down position.

If the defender manages to set down his legs, he can be pushed into bridge position or he can simply escape because he can use his left arm and both legs to establish a counter position.

Momentum with muscular strength dominates the first motion of the attacker. The angular power (P) = $T\Delta\theta/\Delta t$ or $T \cdot \omega$ simply we cannot do correctly because no correct moment arm can be established for these physical properties. Once the defender has been pinned on the mat, the pressure is (Pa) = N/area^2, which is $m \cdot g$/m^2. Both wrestlers have 70 kg mass and the area where their body covers (excluding their legs) is approximately 1.2 m.

For one wrestler, the Newton = 686 N. The newton for both wrestlers is 686 + 686 = 1372 N. Then, the Pa = (1372 N)/(1.2 m)^2 = 952.77 N/m^2 or Pascal (Pa).

10.3.5.5 Fourth Take-Down Technique (Variation of the Fireman's Carry) Both wrestlers are clenched with their arms around their neck (Figure 10.14a). This technique is very similar to the previous one. The difference is the following: The attacker (A) grabs with his left arm the defender's (D) right arm at the wrist level or higher (Figure 10.14b). The difference is that the attacker's right arm surrounds the defender's left thigh behind. In the previous technique, the right arm of the attacker has been introduced between both thighs of the defender.

At the time of the grabbing movement, the attacker will kneel down on his right knee and pull toward him the right arm of the defender (Figure 10.14b). In order to facilitate the technique with the pulling of the defender's arm and the lifting of the defender on his shoulder, the attacker will roll forward (Figure 10.14c). In Figure 10.14c, the pulling of the arm and pushing of the defender's body will be emphasized (Figure 10.14d). Finally, the attacker will be on the defender's chest. He simply moves up his left arm toward the defender's upper arm and moves his right arm under the defender's left armpit tightly holding the defender's left shoulder (Figure 10.14d).

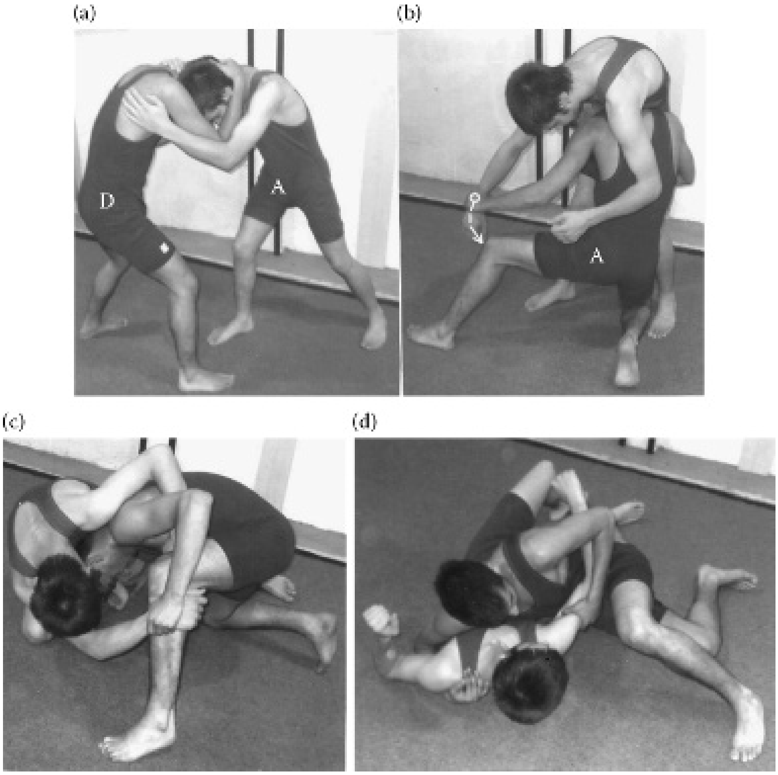


FIGURE 10.14

10.3.5.5.1 Observation of Physical Properties Observing Figure 10.14b, there is an important technical detail for (A). If the attacker grabs (D's) right arm exactly on the wrist there is no chance for the defender to defend with his arm. However, because the defender's arm would be extended, there is more strength needed for (A) to work on this technique. If (A) grabs the defender's arm a little bit higher (on or around the elbow part), then the pulling of (D) will be easier. The right arm of (A) has a role to hold tightly to (D's) body. Practically, (D) has a very limited chance for defense. He can move his right leg far from his left leg. Looking at Figure 10.14c, the defender has a slight chance to defend himself, by introducing his left forearm under (A's) left armpit and try to grab his own right forearm near (A's) grabbing position. If (D) succeeded, this will be a counterkey and he can maneuver his defense more easily.

The most significant motor quality is the strength of the attacker. For the defense, the most important ability is to change body, arms, and leg direction for the best BoS.

10.3.5.6 Fifth Take-Down Technique (Outside Leg Hook with Bear Hug)
Both wrestlers are clenched with their arms around the waistline. The attacker (A) managed to grab the defender (D) in a front bear hug over his arms. This is an advantage for executing not only take-down but throwing techniques too.

In Figure 10.15a, after the attacker secured a hooking position against the defender's right leg, in order to take down (D), the attacker with his left leg must pull the defender's right leg toward him and laterally. When he manages to do this maneuver, he simply must use his weight to push the defender back and down to the mat (Figure 10.15b).

Once (A) is on top of (D), he will force to break the bridge of the defender.

In this technique, the velocity will be calculated by (v) = $\Delta a \cdot \Delta t$. During standing wrestling time coefficient of the kinetic friction of both wrestlers

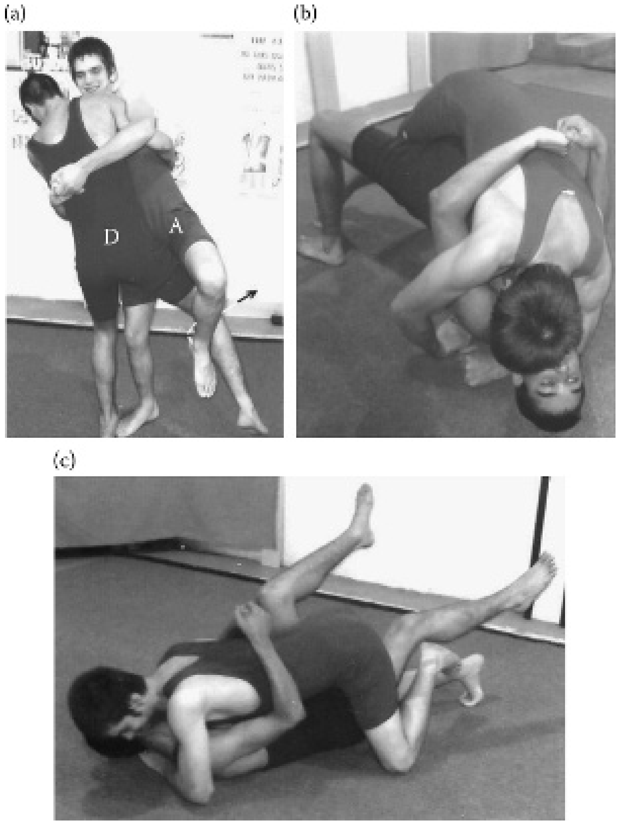


FIGURE 10.15

is high, $\mu_K = 1.02$. To calculate the kinetic friction, recall that the kinetic friction $(f_K) = (\mu_K)(F_N)$.

$$f_K = (1.02)(70\text{ kg}) = 71.4\text{ N}.$$

10.3.5.6.1 Observation of Physical Properties In this technique, there is no momentum involved under the physics $p = m \cdot v$. There is a tug of war at the beginning of the grabbing procedure by the attacker (A). It should be understood that at the very beginning of the tackle by the wrestlers there is momentum and a counter momentum involved every second of contact.

For a successful take down of the opponent, (A) must hook (D)'s right leg, by executing a circular movement from outside to inside and backward. Most importantly, the defender's right leg must be picked up when (A) will incline laterally.

In this technique, when the defender's leg is successfully picked up by the attacker's left leg there is still a lot of force involved by both wrestlers for attack and for defense. The *KE* can be calculated after the defender's leg has been picked up. The vertical velocity is very fast, basically there is no easy or soft take down.

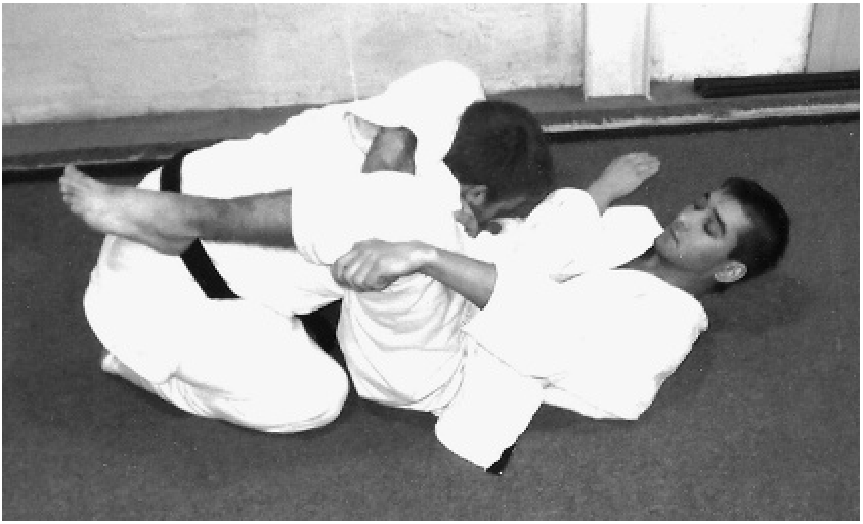
10.3.6 Conclusion about Wrestling Take-Down Techniques

In this book for wrestling, most take-down techniques were described. However, a few of them could be interpreted and executed as a throwing technique. Earlier it has been explained that executing throwing techniques will not necessary assure a victory. This is because when a throwing is executed, two things happen that minimize further immobilization techniques:

1. During most of the throwing, the opponent who falls down will have the contact earlier then the attacker who follows him to immobilize or will be late for action. In this case, the defender perhaps has a second or more to defend himself and counterattack.
2. Throwing also brings the equilibrium problem not just for the defender but also for the attacker. Using mostly take-downs, the attacker has an edge to enter right away into immobilization.

Executing off-balancing maneuvers such as pulling, pushing, and twisting does not assure the attacker that the defender will lose his balance. Fighting for the best grabbing position is the key to make sure your opponent will lose his balance.

10.4 GROUND TECHNIQUES (*NE-WAZA*): JUDO



Judo ground technique. Triangular choke (*Sankaku-jime*).

The aforementioned arts are very much the same. However, to show the differences of each art, one or two techniques will be described. These techniques will show the differences and specificity of the art itself.

10.4.1 Anatomophysiological Considerations

In judo, there are three major groups of techniques that are used in ground fighting:

1. Hold-down techniques (*Osae-komi-waza*)
2. Strangling or choking techniques (*Shime-waza*)
3. Joint locking techniques (*Kansetsu-waza*)

Once the opponent is down on the mat, the easiest technique to apply is the hold-down techniques. The physical effort (strength/force) is considerable. The attacker who managed to pin down his opponent executes mostly a concentric isometric contraction. The muscular effort is mostly intermittent anaerobic and aerobic. The aerobic effort happens when the opponent is moving to escape.

The attacker's forearms and his hands that hold down the opponent mostly are the flexor muscles of the wrist and they are *palmaris longus, flexor carpi ulnaris, flexor carpi radialis, flexor digitorum profundus*, and *flexor digitorum superficialis. Palmar interossei* is a strong adductor of the second, fourth, and fifth fingers and *lumbricals* muscles, which are also flexors of the fingers.

A judoka who is very good in ground fighting and under the attacker can counterattack easily with a choking or a joint locking technique. During the fight on the ground, when none of the athletes managed to have a correct technique for finalization, the judoka who holds the opponent's collar has a possibility to defend or to counterattack very well.

During ground fighting, a judoka tries to protect his collar not to be grabbed. Holding the collar almost in any part, front, back (over the neck), or side, there is a very good possibility to get any kind of combination for subduing the opponent. In ground fighting, both judoka try to find and apply the best leverage position to create the best mechanical advantage.

10.4.2 Objectives

After reading this section, you will be able to understand and do the following:

- Describe the major physical properties or factors that are decisive in ground fighting.
- Explain and describe the major kinematic chains and their actions.
- Explain the most important technical or mechanical movements for the defender and for the attacker.
- Give one or two examples of different levers used and their mechanical advantage, if any.
- Explain the major difficulty and differences to apply an arm bar and a strangling technique.

10.4.3 Biomechanical Principles in Judo Ground Fighting

In ground fighting, the possibility to use any technique or any combination is somewhat reduced in comparison to standing technique for the following reasons:

1. The freedom for space is less than in fighting on standing positions.

2. The judoka who is on his back obviously has less chance to defend or counterattack his opponent.
3. The defender mostly gets his chance to counterattack if the attacker is at the side of the defender or if the attacker is between the two thighs of the defender.
4. In order to get the best leverage, both the defender and the attacker must use their weight.
5. Choosing strangle techniques can be done most easily against the opponent who has the costume (*Judogi*) on. In order to avoid a joint locking technique, the participant should never completely extend his arm. The kinematic muscular chain depends on the technique. There is always an open kinematic chain available for the attacker or even for the defender.
6. Base of support in ground fighting (BoS) is much larger than in fight on standing position when two participants are holding each other in some way; however, the CoG is much closer to the ground and that is why the stability for both participants is very good.
7. The attacker who initiates an attack (being above the defender) should move at least one leg far from the defender for a better BoS.
8. The defender who is under the attacker (to be in a supine or a prone position) and has his arms and/or legs in a pretty much extended position must try to regroup himself to be in a crouched, bent position in such a way that the defender arms and legs are to be close to his CoM. In this way, he can defend himself because
   a. The attacker has less chance to get an arm to be fixed in an arm bar, or to choke the defender, because the defender's arms and legs are close to his body and the attacker cannot manipulate any segments of the body easily.
   b. The attacker also has difficulty to manipulate the defender because he can easily move or roll over any direction and direct his segments easily from his CoM.

The general belief is that if the defender holds his position (arms and legs apart) he has a very good, balanced position. Yes, it is true, but it is also true that he is very immobile and he has less chance to defend himself and to counterattack.

10.4.4 Biomechanical Analysis of the Techniques

Judo's technical myriad arsenal makes it difficult to find the best-suited technique to be described biomechanically to be the defender's or the attacker's role. For this reason, the author has chosen those techniques that are most used in competition and that obviously are the most efficient by bringing the victory to the attacker.

10.4.4.1 Scarf Hold (Kesa-gatame)

This is the very first technique that is taught to every beginner all over the world. This technique is also very successful. There is reduced chance to defend against this technique under the rules of judo competitions. Let us say that both judoka have the right-handed basic grip (*Kumi-kata*) on the kimono. When both judoka are standing and holding the right-handed basic grip, then one of the judoka who throws the other judoka can execute almost any technique.

Recall that your left arm is holding the opponent's right sleeve and you must maneuver the defender after he falls down by pulling his right arm up and close to your left side of the body. When the defender falls down on his back, the attacker should do the following movements successively, smoothly, and rapidly:

1. Pull the defender's right sleeve up.
2. The attacker sets his right knee down on the mats close to the opponent's right side and also puts his right palm down very close to the defender's left side of the neck or even under the defender's neck (Figure 10.16a). At this time, the attacker is almost down on his buttocks.
3. The attacker moves his right leg forward and his left backward as far as possible to have a good BoS. At the same time, his right arm that surrounded the defender's head will tighten the hold and also pull the defender's right arm close to his stomach. By these actions the attacker concluded the (*Kesa-gatame*) holding technique (Figure 10.16b).

10.4.4.1.1 Observation of Physical Properties Before reaching the position shown in Figure 10.16a, there is a short time momentum executed by the attacker (*Tori*) when he pulls up the defender's right sleeve and most importantly when he smashes his right side of the chest against the defender's chest. In this technique, we can mention and describe some forces that are acting on the defender.

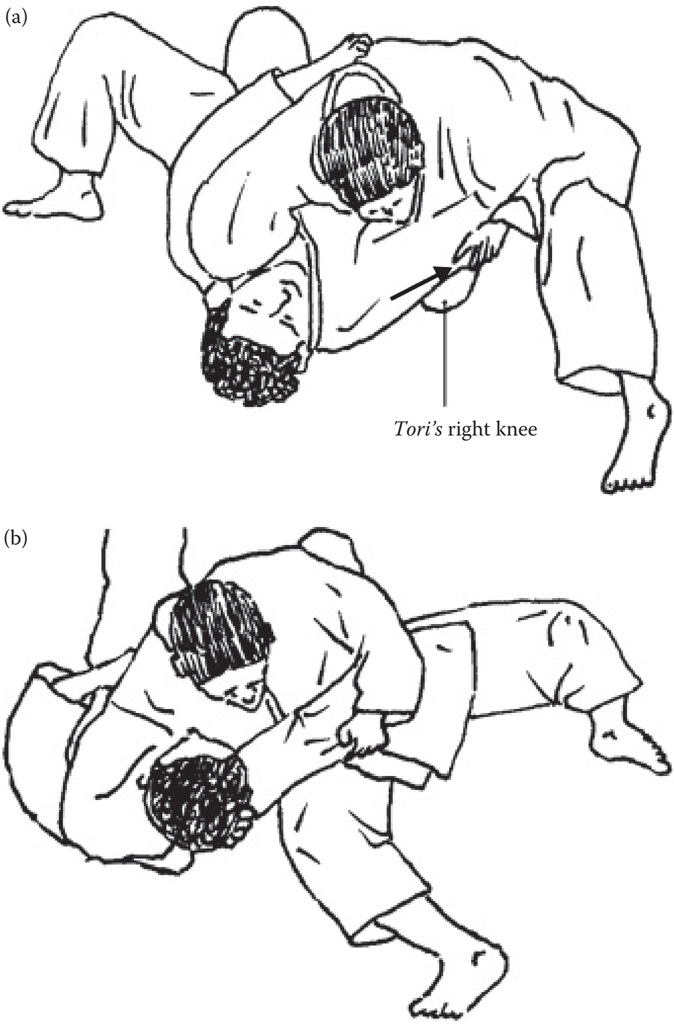


FIGURE 10.16 Scarf hold (*Kesa-gatame*). The arrow shows the direction of pulling by the *Tori's* left hand to stabilize the *Uke* on the ground.

The attacker's static friction force and a little bit of kinetic friction force could prevail if the defender moves all the time for a position to escape.

There is a limited time for linear or angular kinetic energy spent mostly by the defender. The defender pushes back with both his legs and tries to escape by turning his body left or right; then, we can talk about a limited and a very short distance about a linear kinetic energy. As a reminder, linear kinetic energy (KE_{linear}) = 1/2 kg (m/s)^2. For a defender of 70 kg mass,

the velocity of his mass placement could be $v = 5$ m/s. This 5 m/s can be realistic if we use a short distance of the body displacement, such as 0.4 m; then the velocity per second will be less.

How do we reach this conclusion? Here is the calculation: 0.4 m (distance)/5 m/s, then $v = 0.08$ m/s, which gives us the correct velocity for the distance of 0.4 m.

For *KE*, we can use the velocity of 0.08 m/s, then $KE = 1/2(70\ \text{kg})(0.08\ \text{m/s})^2 = 0.224$ J. Obviously the aforementioned example represents approximate numbers.

Note: The defender movement is not exactly linear. It is partially linear and partially rotational because in order to escape from the holding position, the defender must move his left leg step by step and then his right leg to the left by rotating his body to the left. We can shortly state that muscular strength is the predominant physical property.

Mechanical observation: This technique is also used in jujutsu, sambo, and wrestling. However, using the correct leverage, the mechanical advantage is obviously the best in judo where the attacker uses the kimono of the opponent that offers endless opportunity for the attacker to enter in the best holding position. How can the defender escape from this technique? There are several defense techniques. In the following, one such defense technique will be described.

To escape from the (*Kesa-gatame*) technique, the defender will use his left arm that was free during the hold down of the technique. The defender will try to do two things: (1) Pull his right arm from the attacker's left hand grip. (2) Turn to his right and at the same time push the attacker's chin upwards or sideways (Figure 10.17a). With these two actions, the *Uke* will have the chance to turn completely on his stomach and initiate his counterattack. Now, the defender should be on his knees (not on his stomach), and he can initiate a strangle technique (rear choke) against the attacker.

The defender basically created a force couple with his arm's action, by pulling his right arm back toward him and pushing his left arm toward the attacker. The two arm forces apparently do not have the same magnitude; however, it is not the case. Consulting Figure 10.17a, the defender's left arm pushing force is somewhat directed upward and his right arm pulling is directed somewhat horizontally to the ground.

The *defender's shoulders act as a force couple* and not the arms, which are secondary. The defender's left arm pushing force is important because

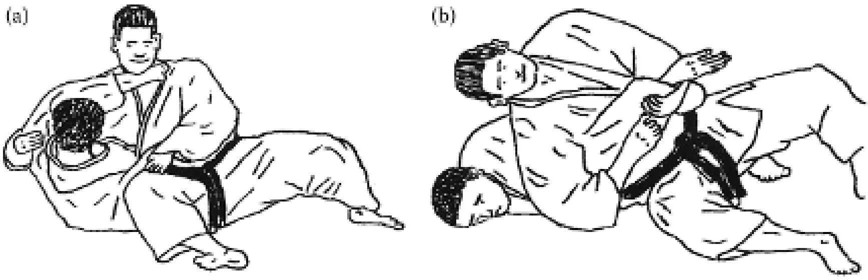


FIGURE 10.17

it creates an opportunity for turning his hips and shoulders away from the previous sideways position.

The attacker has a new opportunity to continue his attack, by pushing the defender's left arm in front of his chin and by grabbing with both palms the defender's arm (Figure 10.17b). The attacker directs the opponent's left arm under his right armpit, and immobilizes the defender again with the technique named "armpit hold" (*Waki-gatame*).

10.4.4.2 Half-Cross Strangle (Kata-juji-jime)

Both judoka are on the ground. The attacker (*Tori*) is between the legs of the defender (*Uke*) who is on the mat with his back (Figure 10.18a). *In this technique, the defender will finalize the choking technique against the attacker* (*Tori*). Each judoka searches for the best grip (*Kumi-kata*). Let us suppose that the *Tori* with his right arm grabbed the *Uke*'s left collar first. As a defensive counteraction of the *Tori*'s attack, *Uke* blocks the Tori's right arm with his left arm and grabs the *Tori*'s left collar. The *Uke* introduces his four fingers into the collar and closing with his thumb at the level of the clavicle of the *Tori*. Immediately without delay, the *Uke* grabs the left collar of the *Tori* with his right palm a little bit higher with his thumb inside the collar (Figure 10.18a).

At the time when *Tori* grabbed the *Uke*'s left collar with his right arm, *Uke* pulls the *Tori* a little bit to his left side in order to off-balance him and to force the *Tori* to use his left palm to set down for counterbalancing his body (Figure 10.18b). In this case, the *Tori* can use only one of his arms, which is the right arm.

Now is the time for the *Uke* to finalize his choking technique. The *Uke* swings his right arm over the *Tori*'s head and gives a tug on his collar. By this action the *Tori*'s head will be forcibly moved down and a little bit to his left (Figure 10.18b). The next move of the *Uke* is to assure his choking position on the *Tori*'s neck by crossing each of his forearms (Figure 10.18c).

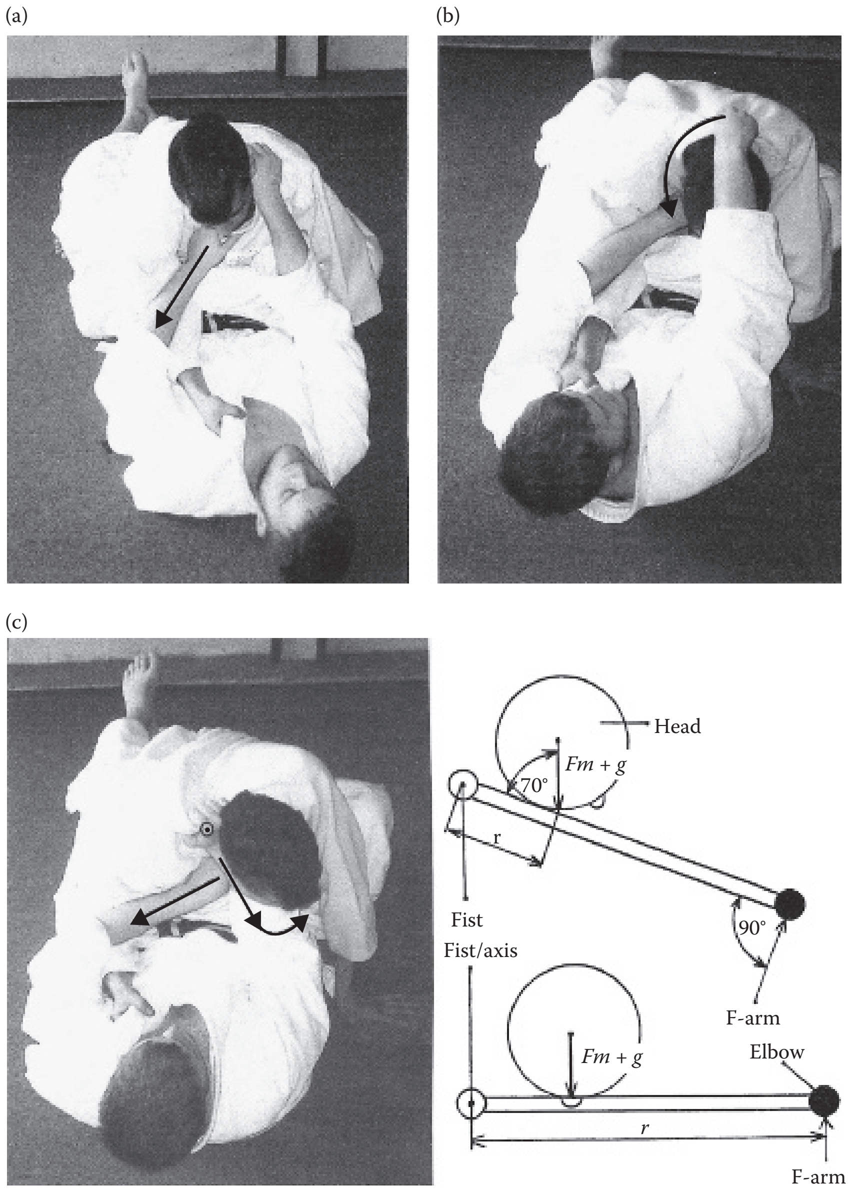


FIGURE 10.18 Half-cross strangle (*Kata-juji-jime*). (a, b) The arrows represent forces and their directions. (c) The left sketch represents the initial position of the defender's (*Uke*) forearm. The double line represents the forearm. The right sketch represents the final position of the *Uke's* forearm. F-arm represents the force moment arm. The circle with a dot in Figure 10.18c represents the fist (fulcrum) of the defender. The Fm + g on the lower right sketch represents the resistance

(d)

FIGURE 10.18 (Continued) force (head of the defender), which is the "mass" + gravity. Observe the circled arrow in front of the attacker head, which shows the action of the right forearm of the defender. (d) Figure represents the final position of the defender being on his right side (on the left side of the figure), who executes the choking technique. The attacker is on all fours and ready to tap out with his left palm on the mat.

For the choking technique to be successful, *Uke* holds his technique and rolls a little bit to his right and sets his right upper arm to the ground (Figure 10.18d). By this action, he can add more force to the choking technique. In addition, the *Uke* will cross his legs over the *Tori*'s body to stop any possibility of escape. *Tori*'s real option is to give up by topping out on the ground or on the *Uke*'s body.

Note: Any choking technique must involve two arms (hands) and/or one arm and one leg (lower leg). The choking usually is initiated in two different ways: (1) The two arms that hold the collar of the opponent's will pull one to the left and the other to the right. By this action the collars will suffocate the opponent. (2) The second action of both forearms that usually accompanies the first action will twist the collar, which is another additional force to be directed by the defender (*Uke*) or the attacker (*Tori*).

10.4.4.2.1 Observation of Physical Properties What kind of physical properties can the defender and the attacker encounter? Analyzing first the attacker, who throws the *Uke*, he obviously has the momentum and also gravity on his side. After setting his body on the defender (*Uke*), he can have the initiative of attacking. In other words, he continues his momentum.

Recall that every action starts with momentum, then turns into impulse in case of contact, which in turn changes the momentum. In our case, once both fighters are together on the ground and the attacker grabs the defender's right collar, the momentum will stop if no pulling, pushing, or twisting action occurs.

Analyzing the attacker's or the defender's action, we can analyze the leverage principle, which is what we humans or machines use to gain maximum output from minimum input. The question is what kind of lever, if any, can be used by the defender? If the pulling of the kimono's collar will help, how can a loose part of any object (*kimono*) be considered as a lever? The lever has been known and described, so we will not analyze this.

To find the correct lever in our technique is not easy. First, we should establish a fulcrum, and then establish the lever, and then obviously establish the force arm and the resistance arm. See Figure 10.18c. The author takes the initiative and establishes the *fulcrum* to be the *right fist of the defender.* The right arm will be the lever of the defender.

The head of the attacker will represent the weight and the gravity (RA). The pushing/moving of the right elbow will represent the force of this second class lever.

Arguments against this leverage establishment exist; however, this is the way the right arm of the defender will work for a correct and efficient technique. Having established the lever for this technique, the question remains what is the left arm's role in this technique.

In Section 10.2.5, the Sticky Hands Combat Jujutsu principles have been described. Principle 9 says "Additional Base," which explains the finding of another base/point that is important in the dynamism of the correct usage of the lever systems in human mechanics.

The left arm of the defender that pulls the left collar of the attacker managed to establish a second base/point that is exactly at the attacker's left side of his neck where the collar is still in contact with the neck. If the defender does not pull the attacker's left side of the collar, then the defender's right arm, particularly the elbow, cannot establish a firm contact for strangulation. It is important to mention that the defender should roll to his right side and not to his left side. If the defender rolls on his left side, then the attacker has the chance to push away the defender's right elbow from strangulation.

Calculation of the forces: Let us say both judoka have a mass of 70 kg. The defender (*Uke*) who is in a supine position under the attacker uses mostly his right forearm for choking the attacker. Previously, the role of the defender's left arm has been explained. The attacker's head that represents

the resistance force has a mass of about 5.30 kg, which is approximately 52 N, and this resistance force at the beginning of the choking has an angle approximately 70° against the lever arm, which is the forearm of the defender. This 70° will be changed at the final position (lower sketch) to 90°. For the force arm (Figure 10.18c, see F-arm), we should use the right shoulder muscle mass, fist, and the forearm mass. For approximate calculation, we use 6.5 kg, which is approximately 64 N. The upper arm mass is excluded; basically, it is used for connecting the shoulder and forearm force. 64 N is an approximate number for a judoka with 70 kg mass.

In both sketches, the defender's forearm, which is the lever, using this force arm (effort arm), always remains approximately at 90° angle. The top sketch radius (r) = 0.2 m, which represents the perpendicular distance between the axis of rotation (right fist) and the line of the resistance force (axis of the vertebral column). The lower sketch $r = 0.37$ m, which represents the perpendicular distance between the axis of rotation and the line of the force (effort arm), which is the elbow.

For the top sketch or first position calculation, we have torque = $(r_1)(F_1)(\sin 70)$, which give us $T_1 = (0.2\text{ m})[(5.30\text{ kg})(9.8\text{ m/s}^2) = 52\text{ N}]$, then $52\text{ N}(\sin 0.93)(0.2\text{ m}) = 9.67\text{ N}\cdot\text{m}$. Has a positive sign for counterclockwise direction (see Figure 10.18c, rounded arrow, which indicates the right elbow movement).

For the lower sketch or final position calculation, we have torque = $(r_2)(F_2)(\sin 90)$, which gives us $T_2 = (0.37\text{ m})(64\text{ N})(\sin 90 = 1) = 23.68\text{ N}\cdot\text{m}$. $F_{\text{net}} = T_1 + T_2 = 33.35\text{ N}\cdot\text{m}$.

Note: As you can see from both sketches, the resistance force changes its angle because of the force arm (*Uke's* right forearm) movement, so we could use for a more proper calculation a sin 80°, which is a median of both 70° and 90°. In addition, the 90° at the elbow has nothing to do with the calculation of the T_2; it just shows the final position of the force arm (forearm). As long as the upper arm is perpendicular to the force arm, the force will be maximum.

10.4.4.3 Entangled Arm-Lock (Ude-garami)

This technique is relatively simple and extremely efficient; however, it is not so easy to perform because for this technique the defender must lure the attacker to get the attacker's arm to be put into the correct arm-lock position. In Figure 10.19a, the attacker on the right tries to push down the defender's right leg at his knee. Basically, this maneuver is effective against

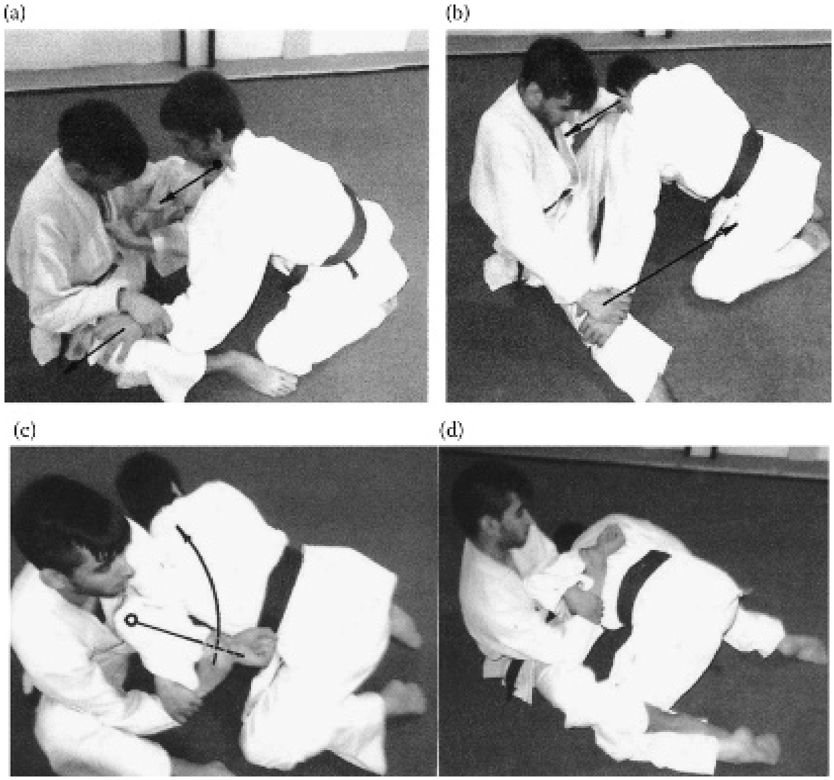


FIGURE 10.19

the defender when both his legs (thighs and calfs) are bent to 90° angle. The attacker should control the defender's left knee too with his right arm or simply with his right knee; however, he holds the defender's left collar presumably to initiate a choking technique.

Why is this move effective? By pushing down laterally on the defender's right knee, there will be a tremendous pain at the groin area, so the defender to release his pain, tries to move the attacker's left arm away (Figure 10.19b). The defender grabs the attacker's left arm at his wrist. When the attacker's left arm is completely extended, then is the time for the defender to attack the extended arm.

The defender should move the attacker's arm backward and upward as high as possible (Figure 10.19c). The attacker's reaction will be to move down and forward his arm or pull it close to his body. At this time, the defender with a sudden move will pull more outside the attacker's arm

and surround the attacker's elbow with his left arm executing an arm-lock technique (Figure 10.19c).

Once the entangled position is fixed, the defender should push the attacker's arm to the left and tightly pull the arm-lock with the left arm more toward himself to be more efficient (Figure 10.19d). To eliminate the attacker's chance for liberation from the arm-lock technique, the defender should move his right leg over the attacker's left leg to control him better.

10.4.4.3.1 Observation of Physical Properties When the attacker tries to push down the defender's right knee, the attacker could lose his momentum and he must now resume defending himself. The defender can create a torque for this technique as soon as he assured the arm lock position. The defender will use for the fulcrum the attacker's left elbow (Figure 10.19c, see the little circle) just like in the previous technique (half-cross strangle).

In the previous technique, the role of the defender's left arm that pulled the attacker's left collar has been explained. In a similar way, in this technique, the defender must assure that the attacker's left elbow will be fixed and remain just for fulcrum. This assurance will be executed by the defender's left elbow pit that can hold very well the attacker's left elbow in a very fixed nonmovable position. We will not describe this technique any further and we will not give any examples. This will be for the reader's discretion.

Note: In Figure 10.19a–c, the arrows show the direction of pushing or pulling forces. In Figure 10.19c, the tiny circle shows the fulcrum that has been described before.

10.4.4.4 Arm Bar (Ude-gatame)

This technique is almost similar to the previous one. The defender on the left side of this technique allows the attacker to push his right knee down (Figure 10.20a). However, at the time of pushing action, the defender extends his leg to avoid the pain from his groin (see the explanation in the previous technique).

At the same time, with the right leg extension, the attacker still has the momentum of pushing the right knee of the defender. For this reason, the attacker's arm will be extended more. At this time, the defender surrounds the attacker's pushing forearm in such a way to be controlled by his right elbow pit. The defender for a better control will pull back his right leg and the thigh will be pushed upward for tightening the elbow pit control maneuver (Figure 10.20b).

FIGURE 10.20

For holding successfully the extended arm of the attacker, the defender will pull forward and down the collar of the attacker and at the same time position himself laterally on his left side and set his right knee on the back of the attacker (Figure 10.20c). The defender will finalize his technique by applying pressure with both palms on the attacker's elbow.

10.4.4.4.1 Observation of Physical Properties Looking at Figure 10.20c, the defender has another choice to immobilize the attacker's left arm. Instead of setting the right knee on the attacker's back, the defender will set his knee exactly on the edge of the scapula on the acromio-clavicular area.

The defender will use the attacker's total arm length as a lever. In order to be efficient with this arm-bar technique, the defender must be strong enough when applying the pressure against the elbow.

10.5 GROUND TECHNIQUES (*NE-WAZA*): JUJUTSU AND SAMBO

Jujutsu technique: arm lock (*Ude-gatame*).

In these two martial arts, the author will not differentiate the ground technique; this is because in both arts the techniques are very similar, except that in sambo, strangling techniques are not allowed. In sambo, the strangling techniques are still taught as self-defense techniques.

10.5.1 Anatomophysiological Considerations

The physical effort is very similar to judo ground fighting; however, because of the attack area, which is much larger (body, legs, and arms); the fighting is going on with more aerobic effort. Obviously when one of the combatant managed to assure a good technical procedure, for example, strangling and is closed to being finalized, then the fighting continue for seconds with anaerobic effort.

In jujutsu or sambo ground fighting, just like in judo, the scope for winning is to apply pain on the defender's joint by twisting, pressuring, or pulling over the anatomical limit of the joint. During the fight when one of the participants managed to attack the opponent's leg, that will

usually be the foot of the opponent. An attack is seldom applied on the knee because the knee is connected to large and strong muscles that are difficult to maneuver into any knee hold, pinning (*Hiza-gatame*), or knee key lock (*Hiza-garami*) technique.

When an attack occurs on the foot to apply a hold or a twist, it should happen in the following way: The attacker should always press down the foot into plantar flexion position. However, there is no guarantee to have success delivering pain to the opponent. If the plantar flexion procedure is accompanied with a twisting of the foot at the ankle level, then the technique will be painful.

When the attacked foot is not pressed into plantar flexion position, then the twisting foot must be in 90° position with the leg. The twisting should be done outside, externally. By twisting medial, the attacked foot has more strength to oppose against the force of twisting.

10.5.2 Objectives

After reading this section, you will be able to understand and do the following:

- Describe the major physical properties or factors that are decisive in ground fighting.
- Explain and describe the major kinematic chains and their actions of the attacker (attacking the arm or leg of the opponent).
- Explain the most important technical or mechanical movements for the defender and for the attacker.
- Give one or two examples of different levers used and their mechanical advantage, if any.
- Explain the major difficulty and differences to apply an arm bar and leg bar.

10.5.3 Biomechanical Principles in Ground Fighting of Jujutsu and Sambo

The fundamental principle in jujutsu and sambo ground fighting is to put your opponent in any fixed position, mostly by using strangle or locking techniques of the arm or leg. The hold-down techniques are also used but for preliminary control of the opponent in order to apply a choking or locking technique, which will assure the victory of the attacker.

Here are the most important principles:

- The attacker can lose his balance easily when he is on the defender's stomach area, such as horse riding position. If the defender is not in a fixed position, he has the chance to toss or push over the attacker from his body by simply executing the wrestler's bridge or simply moving his arm(s) under the attacker's armpit or popliteal space and pushing the attacker away from his body. For example, in the aforementioned case, the defender moves his upper body and especially his arms, lets say under the attacker's right armpit, then pushes the attacker to his left to overthrow him.
- If the defender managed to push his opponent away from his stomach, the following step will be to regroup him and attack the leg of the attacker.
- When the attacker feels that he is overtossed from the opponent stomach, he immediately must depart his leg(s) for a better BoS.
- When the defender sees that the attacker moves one of his legs far from his body, then the defender should attack this leg.
- When the defender is in his supine position and the attacker is between the defender legs, particularly between both thighs, then the attacker has limited attacking possibilities, especially when the defender's feet are interlocked.

10.5.4 Biomechanical Analysis of the Techniques

In Section 10.2, two techniques have been described as take-down techniques, where the attacker fixed the opponent on the ground. The vast majority of jujutsu techniques are always finished on the ground, except throwing techniques, which are similar to judo throwing techniques. A jujutsu standing technique and its finalization on a standing position is extremely difficult. Take an example from any police arrest technique. The arrest technique will always be finalized on the ground. Furthermore, the great Brazilian Jujutsu is also finalized on the ground.

In this chapter, among the ground techniques of jujutsu and sambo, the author will mostly demonstrate jujutsu techniques similar to MMA techniques, where *Judogi* (Judo outfit) is not used.

10.5.4.1 Leg-Entanglement (Ashi-garami) Nr.1

The attacker (noted with the letter "A") is on the left side of the figures and executes a back fist strike (*Uraken-uchi*) as a distraction, forcing the defender (noted with the letter "D") to block the attack (Figure 10.21a). Now the attacker seizes the moment and continues his attack by striking with the left elbow on the top of the *quadriceps* muscle to create pain for the defender (Figure 10.21b).

For the next move, the attacker must be quick because the defender will not hold his right leg in front for a long time. The attacker (A) grabs the defender's right leg with his right arm at the ankle and pulls up toward him, and by holding the foot (Figure 10.5c) twists toward the right, forcing the defender (D) to roll toward his left side. At the same time, (A) steps with his left foot between (D's) legs (Figure 10.5d).

The attacker pulls (D's) right leg down toward the ground in such a way that the dorsal part of (D's) right leg, particularly the lower part of the *gastrocnemius* muscle, is pushed against (A's) left leg frontal part, particularly against the tibia bone (Figure 10.5e).

The last movement of (A) against (D) pulls (D's) left leg and sets his left foot under (A's) left knee (Figure 10.5e). In Figure 10.5f, the attacker pulls up the defender's right foot with his left hand by holding all the toes. At the same time, stabilize (D's) foot by pushing down his calcaneus bone with the right palm.

10.5.4.1.1 Observation of Physical Properties This technique is pretty complicated with so many twisting movements. The attacker has the momentum by taking the initiative with the back fist strike (Figure 10.21a). We are not interested in the small impulse resulting from the strike. This technique contains a lot of strength/force-related movements.

The continuous changing of the different positions until the final position of holding the defender, the attacker uses many different leverages. By using correctly the different leverages, the attacker's kinetic energy consumed will be reduced to a minimum.

Let us analyze the different positions of this technique and find the adequate lever for that position: The first lever usage occurs in Figure 10.21b. The attacker strikes the defender's quadriceps with his elbow and then continues and grabs immediately the defender's right leg at his ankle. At this time, the attacker must push down the knee of the defender to use a lever against the defender, and at the same time he must lift up the defender's leg. The axis of rotation will be at the coxofemoral joint.

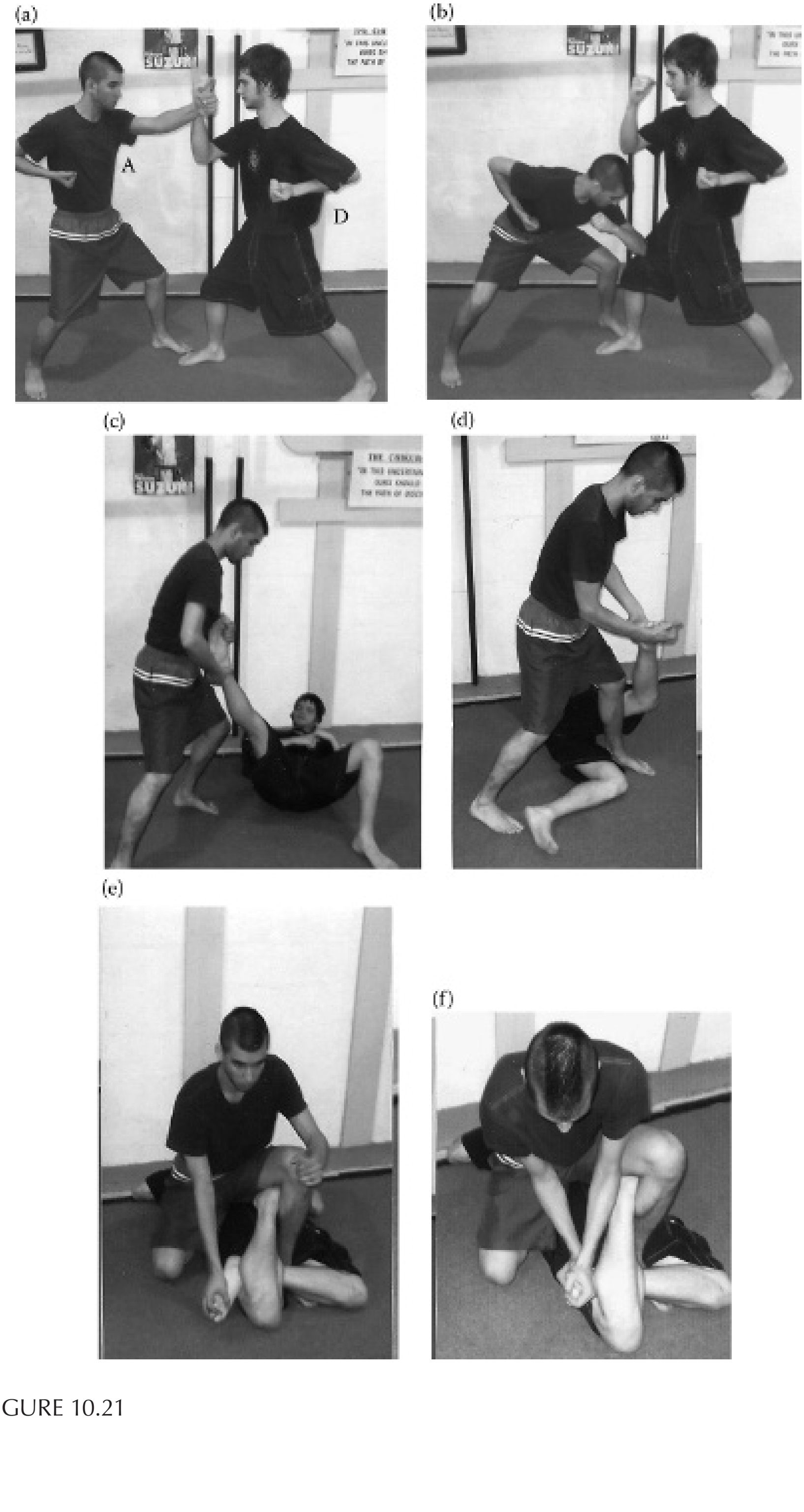


FIGURE 10.21

This lever is considered to be second class, where the weight of the attacker is his total left arm with the pushing down motion. The effort arm of the attacker is his right arm, which pulls up the defender's leg at the ankle. The pushing, pulling/lifting movement is not shown in any figures.

Figure 10.21c and 10.21d shows only the twisting movement of the attacker's arms. Another real lever is shown in Figure 10.21e and 10.21f. Looking at Figure 10.21e, it can be clearly seen that the attacker's limbs creates an ideal second class lever.

The fulcrum is represented by the defender's left knee. The weight is represented by the calf and the pressing action of the attacker's left thigh on the defender's left foot represents the force arm.

Analyzing the physical properties of this technique, nothing significant can be described, such as velocity, acceleration, torques, inertia, power, and so on because the movements are changed continuously all the time also the distances by moving a limb are very short in order to be considered for a calculation of the speed and/or distance involved.

10.5.4.2 Leg-Entanglement (Ashi-garami) Nr.2

This technique is little bit similar to the previous one. The attacker will execute a straight punch (*Tsuki*) against the defender's face to distract the defender's attention from the real attack movement (Figure 10.22a). The defender blocks this punch and will get ready for the counterattack. The attacker continues his real attack on the defender's right leg, hitting with his right elbow the defender's thigh and pulling with his left hand the defender's right leg forward (Figure 10.22b).

The defender will fall down on his back (Figure 10.22c). Figure 10.22c shows the attacker's position on his left knee. The attacker pulls the defender's right leg and with this action advances on his right knee and sets his knee on the defender's middle of the right thigh (medial part mostly) on the *gracilis* and between the *adductor longus* and *adductor magnus* muscles. At this time, the attacker still holds the defender's right leg at the ankle and then pushes the defender's leg toward and above his right thigh (Figure 10.22d and 10.22e).

The defender's right foot will be set at the attacker's right side on the ribs close to the armpit (Figure 10.22e). By inclining forward, the attacker will induce pain on the defender's body: one point on the right thigh (see the arrow) and the other one on the right ankle, which will be forcibly twisted forward (Figure 10.22e). If the defender tries to do something with

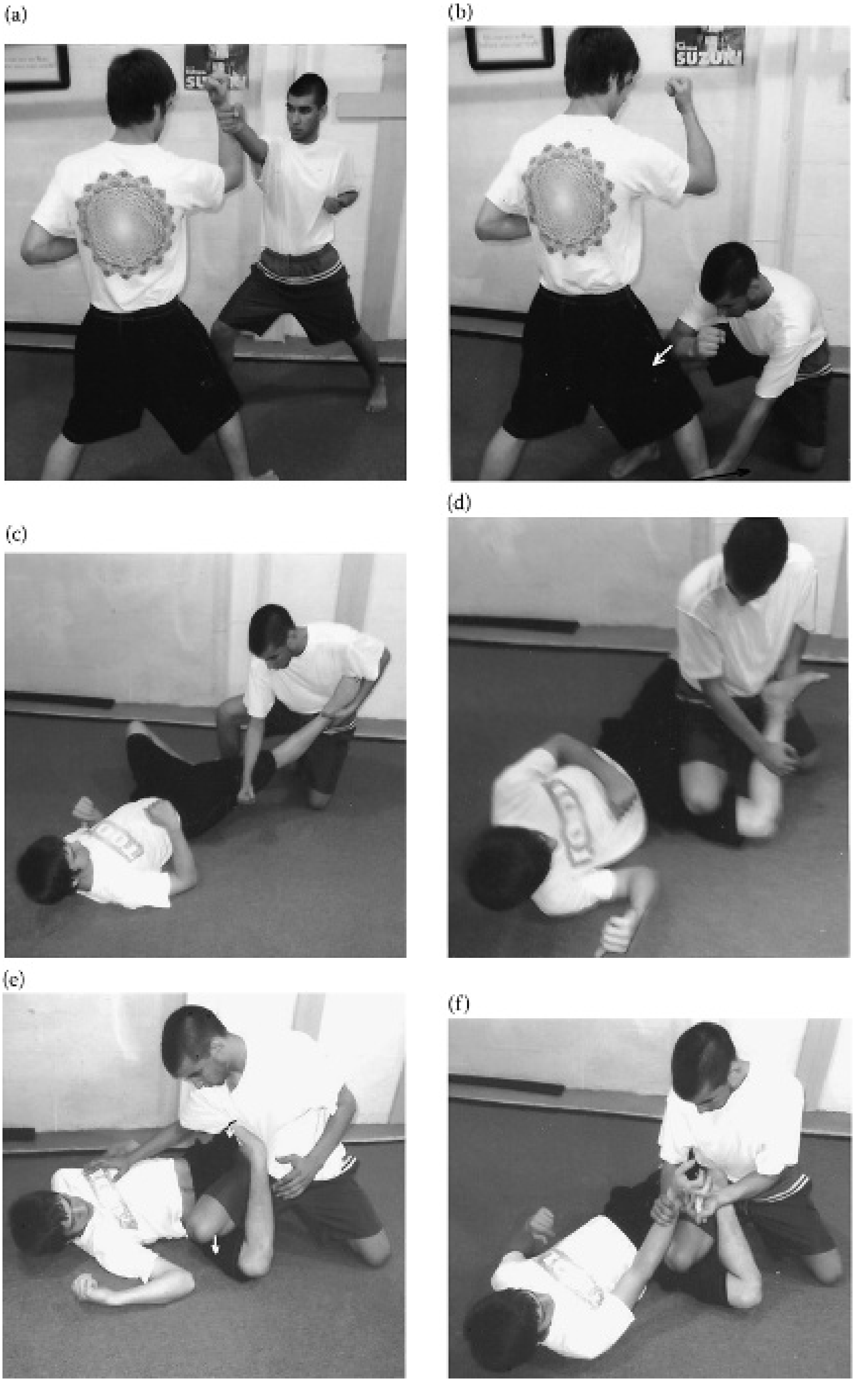


FIGURE 10.22

his right or left arm, the attacker will grab it and forcibly use a technique against his fingers (Figure 10.22f). By this continuous attack, the defender will give up by tapping the mats.

10.5.4.2.1 Observation of Physical Properties This is the second technique where the attacker will execute an immobilization technique on the ground, which can be strangulation, an arm or leg bar or key, and so on. In order to reach to the ground, a real or a fake attack must be executed in order to set up the take-down execution.

The attacker has two extremely painful movements, which is the prerequisite for successful take-down. The first painful movement is by hitting the defender's right thigh with the elbow (Figure 10.22b). The painful spot is at the quadriceps muscle area, precisely on the middle part of the thigh (*vastus intermedius*).

When the defender falls down and is on the back, then the second painful spot is on the medial part of the right thigh, precisely on the *sartorius muscle* approximately at the 1/3rd distance taken from the knee up on the thigh. An observation should be made on this last painful spot; pressing the femur bone almost anywhere along it medial side will cause the fighter to experience pain.

In Figure 10.22c, the attacker pushes above the knee (medial part of the thigh) of the defender in order to create a kind of force couple (right arm pushes down the thigh and left arm lifts up the calf). In this kind of maneuver, the attacker has the chance to bend the defender's knee (Figure 10.22d) and to move his leg under the attacker's armpit (Figure 10.22e).

The energy will be calculated as $PE = m \cdot g \cdot h$, where m is the mass, g is the gravity, and h is the distance from the standing position of the attacker to the ground for immobilization.

10.5.4.3 Rolling Strangulation (Kaiten-jime)

This technique is very effective and relatively easy to execute. When both fighters are on the ground and the defender is on all fours, that is the time to execute this technique. The attacker is at the left side of the defender and he is inclined above the defender's back toward his right shoulder.

The attacker hooks with his left leg the defender's left arm at this elbow pit (Figure 10.23a), the "Aleg" indicates the attacker's left leg hooking action. In Figure 10.23a, "Aa" indicates the direction and route of the attacker's right forearm that will be directed in front of the neck of the defender for strangulation.

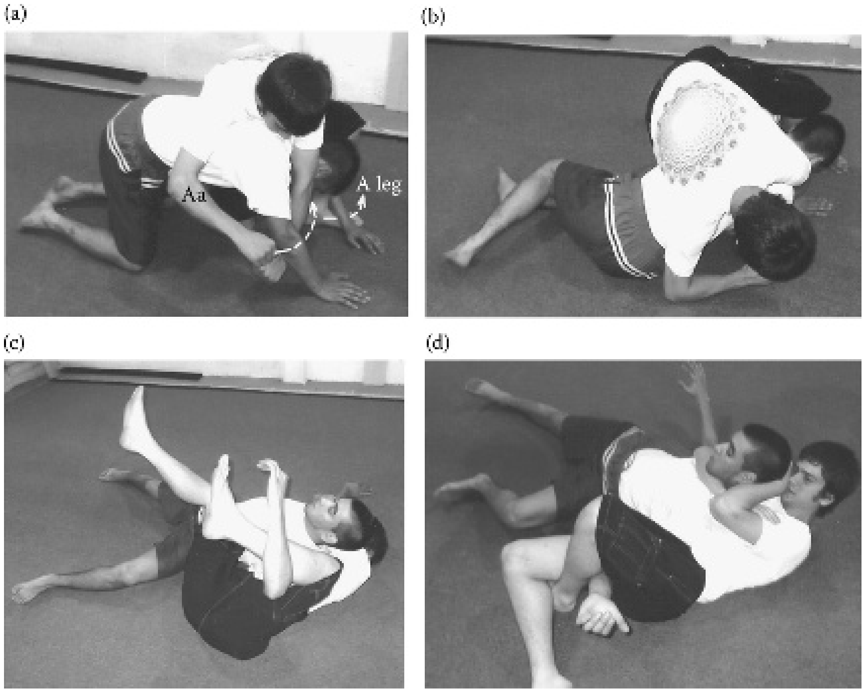


FIGURE 10.23

Figure 10.23b shows the rolling of the attacker over the defender's back. In this figure, the right arm of the attacker is on the ground for a better balance, but will be in front of the defender's neck later.

Once the rolling action of the attacker has been completed (Figure 10.23c), the strangulation starts right away. In Figure 10.23c, it can be clearly seen that the attacker's left leg, which initially hooked against the defender's left arm at the elbow pit, has a good control over the left arm.

The strangulation will resume with the attacker holding back his right forearm against the defender's neck (wind pipe), and setting his right fingers into his left arm elbow pit. Then the attacker will move his left forearm over the defender's neck and the full left palm will press forward and down the defender's neck choking him.

10.5.4.3.1 Observation of Physical Properties At the beginning of this technique, the defender can oppose against the rolling of the attacker by moving his right arm far right to enlarge his BoS. However, this maneuver is good for a very short time, especially when the attacker is hooking the defender's left arm and when he managed to set his right forearm in front of the defender.

At the time of rolling, the attacker has a short angular momentum $L = I \cdot \omega$. The attacker rolls through his frontal axis. The defender rolls through his longitudinal axis. The defender has a smaller angular rotation than the attacker. To calculate the moment of inertia, the defender has his spine as the axis of rotation. The two coxofemoral joints are considered to be the attacker's axis of rotation. Because the rolling speed is minuscule we will not calculate either the moment of inertia or the angular velocity. During rolling, the mass of the defenders and/or the attackers is steady just like the velocity. In this case, the moment of inertia is steady during rolling.

If the arms are moved far away from the defenders or the attackers during rolling, obviously the speed will decrease and the moment of inertia will be larger. In this technique, the arms are kept close to the body for two reasons:

1. When the arms are kept far from the body, the moment of inertia will be high (rolling will be slower).
2. By having the arms far from the body, especially the defender arms during rolling, injury can occur; however, the attack will be more difficult, because the BoS is wider.

After the rolling, the major motor quality is the strength mostly under aerobic endurance. The defender fights for the liberation of the choke hold under anaerobic endurance.

10.5.4.4 Attack with "Arm Wheel" (Te-guruma) and Immobilization with "Ankle Key" (Ashi-kubi-garami)

This technique also belongs to the take-down techniques. The focus on physical properties will be twofold (take-down and ground technique). The defender is on the left side of each figure and temporarily (he) executes an attack. The role of the attacker will be the take-down "arm wheel" (*Te-guruma*) technique and the role of the defender will be a counteraction with a finalization of an "ankle key" (*Ashi-kubi-garami*).

The defender attacks with a straight punch (Figure 10.24a). The attacker will block the attack by ducking down, and then grabbing the defender with his left arm surrounding the waist of the defender and the right arm grabbing the defender's left leg at the popliteal space or a little bit higher (see Figure 10.24b). Now the attacker picks up the defender (Figure 10.24c).

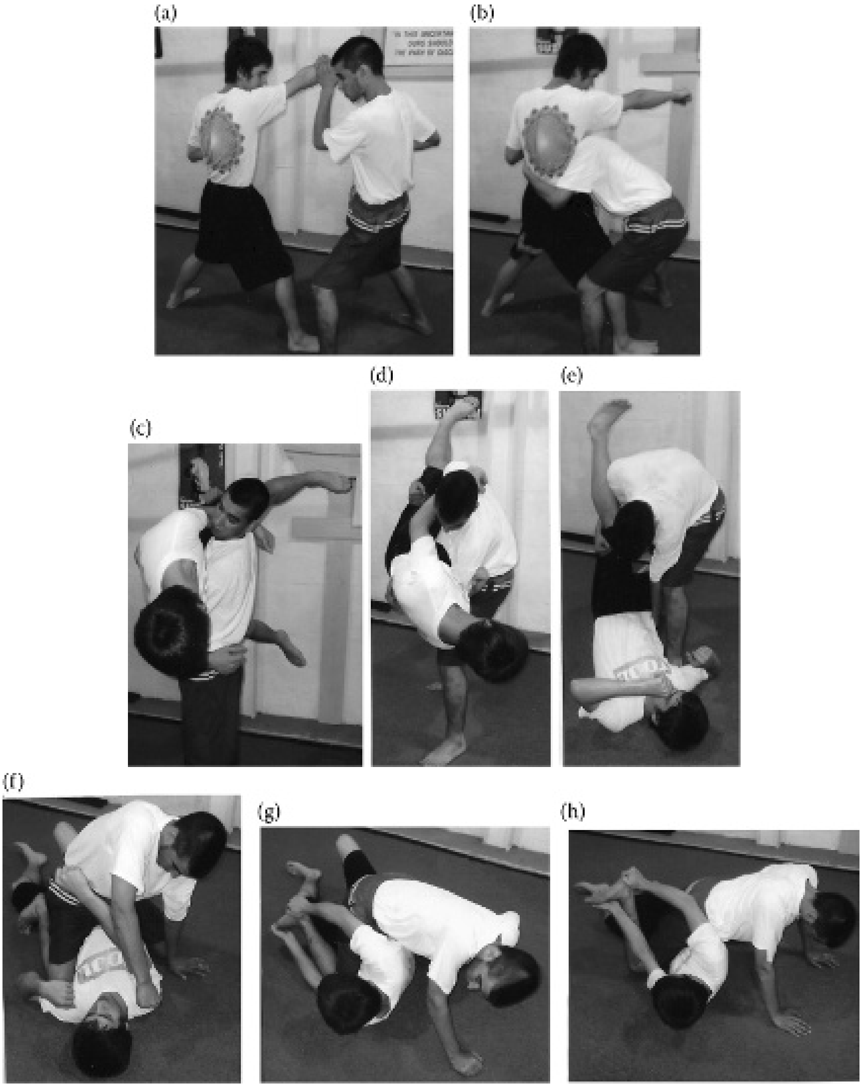


FIGURE 10.24

The attacker still holds the position described before; however, he will drop the opponent as seen in Figure 10.24d and 10.24e.

After dropping the opponent, the attacker will be over the defender's chest (horseback riding position) (see Figure 10.24f). The attacker will punch with his right arm toward the defender. The defender will deflect the punch (Figure 10.24f) and inclines his body forward and toward his left, grabs the attacker's right foot with both hands, and starts to twist the foot to inflict pain.

The twisting action will occur in the following way: The defender grabs the toes with his left hand and the heel with his right hand (Figure 10.24g), then pulls the toes toward him and presses forward the heel of the attacker (Figure 10.24h). The defender has an extra option defending himself: before grabbing the attacker's right foot, he can strike with the right elbow to the right kidney of the attacker. In Figure 10.24h, the chance of the defender to hit the attacker's kidney can be clearly seen. Hitting the kidney is prohibited; however, it is used for the purpose of self-defense.

10.5.4.4.1 Observation of Physical Properties When the attacker picks up the defender, he has a linear momentum that will turn to be an angular momentum. By picking up the defender, the linear momentum is slow because it is against gravity. When the execution turns angular, the angular momentum will turn to be very fast because of the rotation of the defender's body.

However, this technique has a very short time angular velocity. As soon as rotation starts, the dropping will occur by the attacker and is helped by gravity. In this technique, the gravity exclusively has the primary role because force from the attacker is almost none by dropping his opponent.

The attacker has two chances to take down the defender:

1. Drop the opponent from chest height. Choosing this option, the attacker can successfully continue his attack mostly with punching techniques because the distance between the attacker and the defender became larger and this creates an ideal opportunity for the attacker to continue his attack with any punching techniques, which can be easily accelerated.

2. Take-down by guiding a little bit slower (Figure 10.24e). By choosing this option, the attacker can continue his attack mostly with holding-down techniques because the two opponents have the *permanent contact/link* and by this, almost any simple attack or combination can be executed more easily than by dropping an opponent down and then attacking him.

The angular rotation of the defender will be through his sagittal axis. With this (see Figure 10.24c), the defender's moment of inertia will be very large because his legs are separated and both are very far from his CoM.

We can mention a little torque; however, the precise axis cannot be determined exactly. Presupposed the axis of rotation can be through the abdomen of the defender, but the moment arm (force or resistance arm) cannot be determined exactly because the legs and the core of the defender. Let us look at Figure 10.24c; there is a rotation through the sagittal axis; however, from Figure 10.24d, the defender's body does not rotate anymore; the body slides down from the attacker's grabbing hands.

Analyzing the figures we can realize that this technique has a very short time of angular rotation. The rotation starts when the attacker picks up the defender's body from the position (see Figure 10.24b), and then continues approximately until the position (see Figure 10.24d). This is an insignificant body rotation of the defender, from where the linear movement of the dropping down the defender's body starts again.

Let us calculate several physical properties: To calculate the moment of inertia or the *KE*, we know the defender's body mass is 70 kg, but we do not know the precise axis of rotation, which is important to calculate the moment of inertia and the angular momentum. In our case, we cannot even use a presupposed number or location for the aforementioned physical properties.

We will abandon these two equations. Calculate the linear momentum when the defender is dropped and not when the defender is picked up. $(p) = (\text{kg} \cdot \text{m/s}) = (70\ \text{kg})(0.49\ \text{m/s}) = 34.3\ \text{kg} \cdot \text{m/s}$. The 0.49 s represents an average velocity. The calculation of the defender impulse at the time of contact with the ground will be impulse $(J) = F\Delta t = p = m\Delta v = m\,(v_f - v_i)$.

In our case, the returned force time we cannot check it out, we assume that has a very long time of contact, and because the body will remain still after the contact with the ground (there is no rebound at all). In order to calculate the precise impulse, if you do not enter into the details of impact, you cannot get the precise answer. Human bodies are not billiard balls.

Note: To calculate the force when the opponent is dropped down, the gravity and the mass of the opponent should be counted. Calculate power $(P) = F \cdot \text{m/s}$. Then, for the opponent, $[(70\ \text{kg})(9.8\ \text{m/s})](0.49\ \text{m/s}) = 686\ \text{N}(0.49\ \text{m/s}) = P = 336.14\ \text{W}$.

10.6 GROUND TECHNIQUES: WRESTLING

Wrestling ground techniques differ greatly from judo, jujutsu, and sambo techniques. In ground techniques of wrestling, the objective is to pin your opponent with both his scapulas to the ground. In judo, jujutsu, and sambo, the attacker can use not only pinning techniques, but also strangling and arm/leg joint techniques.

The attacker who throws his opponent has a great chance to pin his opponent to the ground. The attacker who executes only a take-down technique has only 50/50 chance of pinning his opponent. By throwing the opponent, the defender must first deal with his balance during the flight of the throw and then he has to immediately find a good balance of defense on the ground. The defender who is not thrown but only taken down, for example, Figure 10.22a–f, has a good chance to defend himself because during take-down he can maintain his balance better than during a throwing technique.

10.6.1 Anatomophysiological Considerations

Usually more effort is required in ground fighting of wrestling than in ground fighting of judo, jujutsu, and sambo. This is because in wrestling there is no immediately available firm grabbing possibility to conclude a correct technique to be finalized. A wrestler must grab a large muscle part of his opponent. The muscle part is slippery because of the perspiration of the wrestler and also the forearm flexors are not fully used to be effective in any grabbing technique.

The fight is combined with aerobic and anaerobic effort. The Greco-Roman wrestler's upper body part from the hip girdle and up, including the neck and arm muscles, must be well developed equally, giving importance for the shoulder, upper arm, lower arm, and so on. It is obvious that the large muscle segments such as *trapezius, triceps, biceps,* and so on are used for the initial attack of grabbing and for the final immobilization. However, the forearm muscles, especially the flexors, should have a good endurance to hold the initial grabbing position.

In Sections 10.3 and 10.4, the neck and forearm muscles have been described, which are the same participating muscles during ground fighting in wrestling; therefore, we will not describe here again.

10.6.2 Objectives

After reading this section, you will be able to understand and do the following:

- Give examples of leverage in bridge holding technique.
- Explain how a defender can escape from a bridge holding position. Give examples.
- Explain if any lever is used by the attacker during a bridge holding technique.

10.6.3 Biomechanical Principles in Ground Fighting of Wrestling

Wrestling ground fighting principles differ greatly from jujutsu and sambo. In these martial arts, the hold-down techniques are just used as preliminary positions because the pinning of the opponent will not count for victory. In wrestling, however, pinning down and holding the opponent is the only option for victory. In wrestling, you can never see that an attacker is on the top of the defender (horse stance position).

Here are some of the principles:

- The attacker should definitively be at or on the area of the shoulders of the defender.
- If the defender is already held down in bridge position, then the attacker besides pushing the defender's shoulders down must also pull the defender's shoulder horizontally in order to break the bridge position.
- When the bridge position is broken, the attacker immediately must position himself with his upper body (particularly with his shoulders) close to the defender's shoulders.
- Wrestler's neck muscles are so strong that they can hold the bridge for a very long time even under anaerobic effort. In order to break the bridge position of the defender, the attacker must have a very good control technique of holding and this technique should not be changed at all in order not to jeopardize the successful hold down of the opponent in case.
- The half-Nelson technique is a very easy technique and is recommended often in Greco-Roman style.

10.6.4 Biomechanical Analysis of the Techniques

The wrestling techniques repertoire is reduced in comparison to judo, jujutsu, and sambo techniques. In Greco-Roman style, the wrestler is handicapped in the take-down executions because leg grabbing techniques

are totally prohibited. In this case, the motor quality, which dominates the wrestling time, is the "strength/force" of the wrestler.

In Free Style wrestling, the technical repertoire is much larger than the Greco-Roman style technical repertoire. A Free Style wrestler mostly attacks using his legs against the opponent legs, such as hooking, scooping, and sweeping techniques. Once the defender is down on the mat and the attacker has the opportunity to continue his attack, he can use the same technique as the Greco-Roman wrestler against the upper part of the body and/or attacking the leg of the defender using the arms rather than using the legs for wrap around for temporary immobilization.

10.6.4.1 Greco-Roman Nr.1 Technique (Half Nelson with Body Rolling)
The defender is on all fours. The attacker is at the left side of the defender and is applying a half Nelson technique (Figure 10.25a). The attacker should press the defender's neck very hard and roll the defender's entire body (CCW) through his longitudinal axis (Figure 10.25b). The attacker

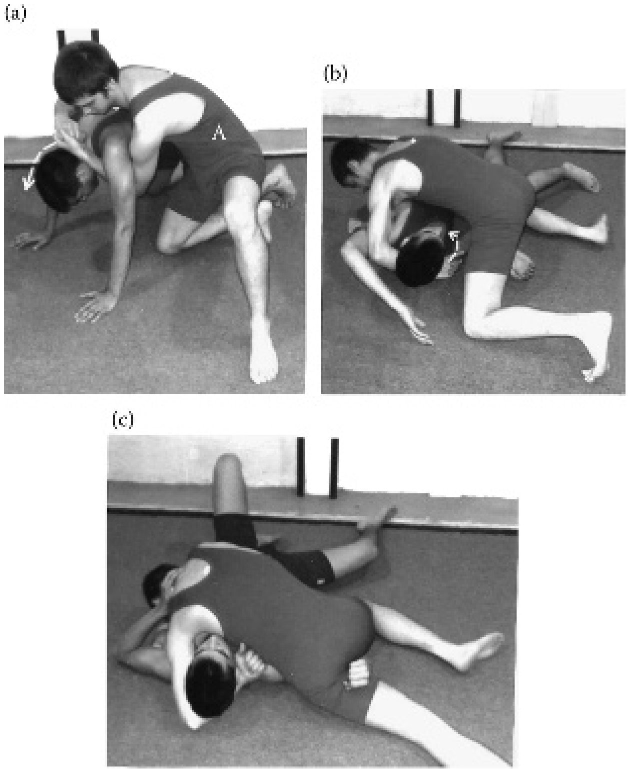


FIGURE 10.25

continues his pressing against the defender to make sure that the defender will be in a supine position (Figure 10.25c).

During the rolling process, the attacker's left arm should remain under the defender's neck. The attacker now has the opportunity to close the defender's head between his upper and lower arm. The defender's head is in the left elbow pit of the attacker (Figure 10.25c). The defender's right arm is under the attacker's left thigh (Figure 10.25c). The defender is not allowed to lift his opponent by using his right arm in Greco-Roman wrestling.

The attacker in order to avoid being overtossed should extend his left leg completely in this way so that his BoS will enlarge. The attacker's right leg should be moved to the right too.

Many times, Greco-Roman wrestlers make mistakes of grabbing the prohibited area of the opponent; however, these mistakes remain temporary and they will be changed very fast in order to avoid penalties.

10.6.4.1.1 Observation of Physical Properties Apparently is a simple technique; however, the muscular strength must be applied against a very strong part of the human body, which is the neck. The defender to defend himself will move apart his arms to enlarge the BoS and moves his right leg far from his body in order to have an even better BoS. The rolling of the defender is executed through his longitudinal axis and will describe 180° or 3.14 rad (rotate from a prone position to a supine position).

The rotational kinetic energy of the defender $KE_{ang} = 1/2\ I \cdot (\omega)^2$. If each wrestler has 70 kg mass, we will use the radius for rotation of the abdomen area. The circumference (C) of the abdomen can be 0.94 m, then the radius $(r) = 0.15$ m, which was calculated from C/π/2. Then, $KE_{ang} = 1/2\ \Sigma[I = (70\text{ kg})(0.15\text{ m})^2][(3.14\text{ rad}/1.2\text{ s} = 2.61)^2 = 6.81]$. Then, $KE_{ang} = 1/2(70)(0.022)(6.81) = 5.24$ J. The 1.2 s represents an average ω velocity.

Establishing a lever at the beginning of the twisting of the body with half Nelson technique can be considered a second class lever. The fulcrum is at the left elbow pit of the attacker; the force arm is considered to be the attacker's left forearm and 1/4th of the attacker's right forearm from the two fists clenched. The effort is directed downward. The resistance arm is extremely short and we consider just as a point (muscles of the neck) of the neck of the defender acting upwards against the attacker force and against gravity.

10.6.4.2 Free Style Nr.2 Technique (Half Nelson with Leg Grabbing)

Looking at Figure 10.26a, the attacker's right palm is on the defender's neck. The attacker has two choices to grab the defender's left leg at the ankle level:

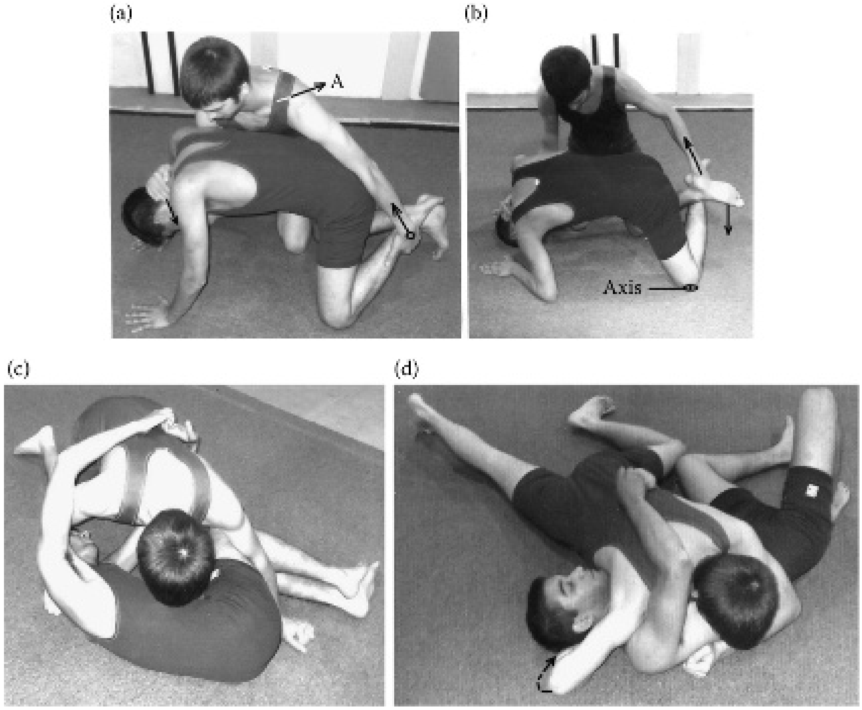


FIGURE 10.26

the first choice (Figure 10.26a) if that the grabbed left leg of the defender's is pulled above his right leg. The advantage of this grabbing is that it can be grabbed very fast and easily; however, the defender could oppose vigorously by moving his right leg toward his right to make up a better BoS.

The second choice (Figure 10.26b) is that the grabbed leg should be under the right leg of the defender. The advantage of this grabbing is that to turn over the defender will be easier than the previous grabbing procedure because the right leg of the defender cannot do any counteraction as it has been immobilized. After the defender has been turned over (Figure 10.26c), the attacker with his right arm will surround the defender's neck and immobilize him on the mat (see in Figure 10.26d the small arrow at the attacker's right elbow).

10.6.4.2.1 Observation of Physical Properties Consider again that the defender's body will be rotated around his longitudinal axis. Because the legs and arms are not in the same line with the longitudinal axis, the moment of inertia will be great. Analyzing Figure 10.26a and especially

Figure 10.26b, the left calf of the defender serves as a lever. If the legs and the arms would be departed from the defender's body, then the overturning of the defender's body would be very difficult.

In Figure 10.26b, the left knee of the defender is the axis, the left arm of the attacker works as a moment force arm (FA), and the defender's right leg, which pushes down the pulling action of the left arm of the attacker, acts as an RA. This is a second class lever. The arrows show the force actions, except in Figure 10.26a, the top arrow just indicates the letter "A," which means attacker.

10.6.4.3 Free Style Nr.3 Technique (Half Nelson with Arm Pulling)

Looking at Figure 10.27a and 10.27b, the reader will not see a big difference between the two figures. However, the two techniques seen in both figures make a great difference in defense. In Figure 10.27a, the defender's (D) right arm is further away from his right leg (knee). Using this position, the defender can enlarge the BoS and counterattack. Figure 10.27b is more advantageous for the attacker because the BoS of the defender is not wide.

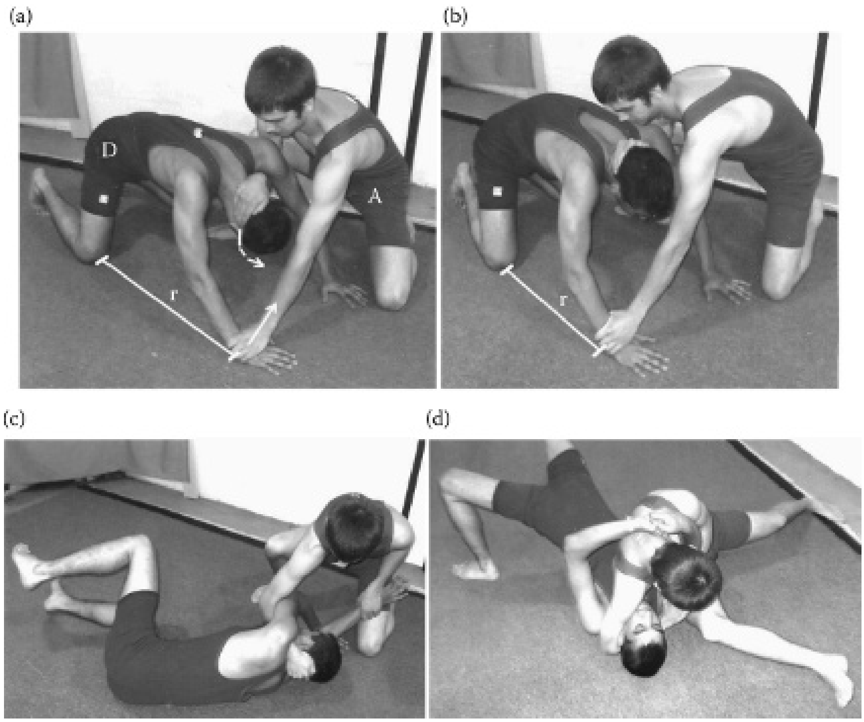


FIGURE 10.27

So, the rolling of the defender can be done easily. See and compare both figures related to distance "*r*."

In Figure 10.27c, the rolling of the defender is almost complete. The attacker (A) does not change any position of his arms. In Figure 10.27d, the defender tries to execute a bridge to avoid to be fixed down on the mat.

In Figure 10.27c, (D) is ready to be fixed to the mat by (A). If (D) does not pull out his left arm trapped between the right upper arm and the forearm of (A's) holding position, he will have difficulty to defend himself. Figure 10.27d shows the final position of both wrestlers.

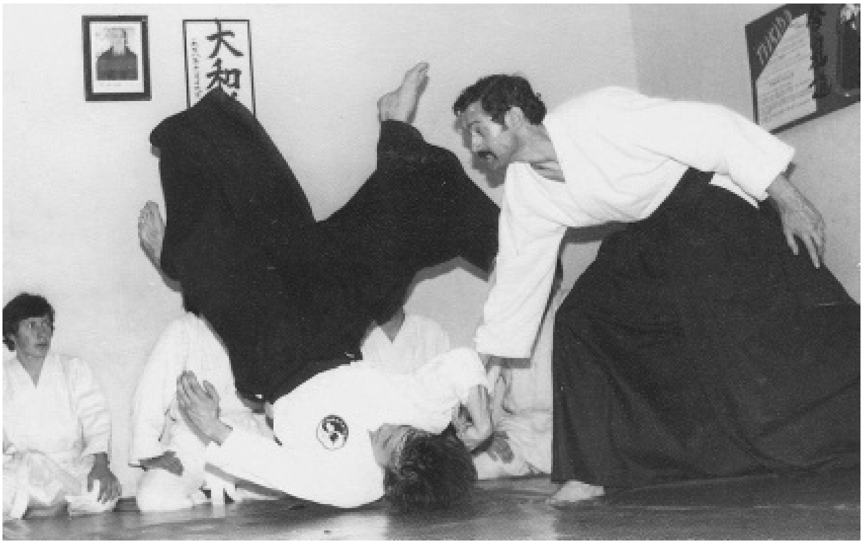
10.6.4.3.1 Observation of Physical Properties In this technique, (A) uses a lever by his right forearm on (D's) neck. The axis could be the neck of (D) or the armpit of (D); it depends on the circumstances such as the following:

1. If (D's) neck can be moved down, then the axis is (A's) elbow pit. The moment force arm (FA) is (A's) forearm ending at the neck of (D) and the RA is (D's) shoulder (second class lever, seen in Figure 10.27a). In this variation, (A's) force arm (forearm) *acting down* and (D) with his shoulder *acting upward* kind of releasing the pushing action of (A) against his neck.

   This kind of second class lever is a contrary movement in the leverage actions because the resistance arms act almost always with gravity (downward) and with the combination of the weight of the object/person in case.

2. If (D's) neck cannot be moved at all, then the axis can be considered the neck itself. In this case, the moment force arm (FA) is again (A's) forearm ending at the elbow pit of (A). The RA is the shoulder of (D); it is again a second class lever (Figure 10.27b). In this variation, (A's) forearm *acts upward* against (D's) left shoulder by lifting the opponent to turn over in his longitudinal axis and the resistance arm of (D's) shoulder *acts downward*.

10.7 AIKIDO AND AIKIJUJUTSU: THROWING AND IMMOBILIZATION TECHNIQUES



Aikido; four-side throw (*Shiho-nage*)—(executed by the author).

Aikido and Aikijujutsu are real martial arts. They are noncompetitive arts. The techniques that are used are quite dangerous, especially in Aikijujutsu. A short explanation will be described herein for the reader to know the basic difference between these arts.

The majority of the techniques that are used in Aikido are directed against the opponent's wrist. In Aikido, it is forbidden to attack against fingers, and hard punching techniques against the face are also excluded. To hit or press vital areas such as the groin, kidneys, liver, and neck is excluded too. In Aikijujutsu, twisting motion on the fingers, shoulders, and many other vital areas is allowed. Obviously, these areas are attacked with the utmost care and gentleness during a training session.

In Aikido, there are also take-down techniques where the opponent's arm is immobilized in a standing position. Then the attacker will guide the defender down to the mat. The immobilization technique used in standing position can be turned into a throwing technique, and when the defender is down on the mat, he can be immobilized with the same technique that has been used in a standing position. An example is the technique of the "arm pin" (*Ude-osae*) or (*Ikkyo*), which will be described later on.

Aikido and Aikijujutsu are not as diversified as karate, where many styles are known, and the terminology also differs a little bit. In Aikido, there are only two major schools known in the world. The first one is the Aikido's founder Morihei Uyeshiba School headquartered in Tokyo and headed by his son Kisshomaru Uyeshiba. The second well-known Aikido system is the Yoshinkan, also headquartered in Tokyo. There are other two Aikido systems that will not be mentioned in this book. The terminology is used in this book is from the original Uyeshiba's terminology. In order to be familiarized, the author succinctly describes the techniques of Aikido.

10.7.1 Classification of the Aikido Techniques

1. Throwing techniques (*Nage-waza*). There are four basic techniques under throwing techniques:

   - Entering throw (*Irimi-nage*)
   - Wrist out-turn throw (*Kote-gaeshi*)
   - Rotary throw (*Kaiten-nage*)
   - Four-side throw (*Shiho-nage*)

   There are also another 8–12 throwing techniques with different variations.

2. Locking and pinning techniques (*Katame-waza*). There are four basic techniques under locking and pinning (immobilization) techniques:

   - Arm pin (*Ude-osae*) or *Ikkyo* (first control)
   - Wrist in-turn (*Kote-mawashi*) or *Nikkyo* (second control)
   - Wrist twist (*Kote-hineri*) or *Sankyo* (third control)
   - Wrist pin (*Tekubi-osae*) or *Yonkyo* (fourth control)

   There are also many different exercises mandatory in Aikido and Aikijujutsu.

10.7.2 Anatomophysiological Considerations

The physical effort is greatly reduced. The effort is totally aerobic and has a short duration. The attacker (*Shite*) usually executes simple movements for an attack, such as a strike forward or laterally or simply grabs

the defender's (*Uke*) arm or collar. The defender has two basic choices to execute any kind of defensive movement:

- With the defensive technique chosen by the defender, he can use a "positive" motion (*Irimi*), which means a straight entering line as a defensive movement into the attack.
- The other possibility of the defender to defend himself with a "negative" motion (*Tenkan* or *Ura*), which means an avoiding movement laterally and circularly from the attacker's attacking movement.

10.7.3 Objectives

After reading this section, you will be able to understand and do the following:

- Describe the concept of *Irimi* (positive) and the *Tenkan* (negative) defensive motions.
- Give one or more examples of leverage during a throwing and a pinning technique.
- Explain how important is the equilibrium in Aikido.
- Explain which muscle group is the most important in Aikido and why.

10.7.4 Biomechanical Principles in Aikido and Aikijujutsu

1. All actions are dynamic. The methodology of teaching is also dynamic. In judo, for example, to learn a hip throwing technique, the beginner (defender) can stay in a static position and only the attacker uses a dynamic action in order to throw the defender.
2. The attacker or defender (does not matter what technique is used) must lose his equilibrium in order to guide his opponent and later on to regain his equilibrium for the finalization of the technique.
3. Aikidoka's position is always high for the better-movement actions.
4. Almost all the techniques can be executed as "positive" or "negative" actions. There is only one technique "heaven and earth throw" (*Tenchi-nage*) that is executed only as positive action.
5. Grabbing the kimono in attack is seldom done and grabbing the kimono in defense is never done.

6. In Aikido, in order to use a lever, first the attacker must use a twisting against a certain joint(s).
7. The majority of vital points (*Kyusho*) attacks, such as hitting, pressing, and twisting, are done against the forearm, particularly against the lower forearm (wrist).
8. Once the forearm vital point is attacked, the forearm is always lifted up to the shoulder's level for two reasons:
   a. Any arm that is lifted up has the tendency to move down, and then it can defend against the particular attacking technique. By holding up the defender's arm, the defense will be very difficult.
   b. Any arm that is raised higher than the shoulder level must first fight against gravity and second against the technique.
9. Calculation of different physical properties can be done under linear or rotational kinetics. Calculation for speed, velocity, distance, and displacement under linear kinematics cannot be done accurately because the measurement of the aforementioned physical properties is difficult due to extremely short time and distance.
10. In Aikido, there are no so-called preliminary actions like in judo. The off-balancing and the preparation motions coincide. Almost all the time, the off-balancing is self-made.

10.7.5 Biomechanical Analysis of the Techniques

It is important to mention the vast diversity of the preparatory exercises, such as postures, distancing, body shifting, different hand work, breakfall, different flexibility exercises for the wrist and other part of the body, and breathing exercise for directing and leading the "vital force" (*Ki*). Aikido under Master Morihei Uyeshiba had many philosophical, esoteric, and direct meaning. One was the reunification of the world with God or, simply explained, the reunification of the nature with God or Aikido.

10.7.5.1 Throwing Techniques (Nage-waza)

Before describing and analyzing any throwing technique, a specification is important. In judo, an attacker who throws the opponent or immobilizes is named *Tori*. The opponent who opposes is a defender and is named *Uke*. In Aikido, these roles are inversely described.

For example, an Aikidoka who grabs a hand or tend to hit an opponent is named the *Uke*; the other Aikidoka who defends against the grabbed arm or against a hit and then throws or immobilizes the *Uke* is named *Shite* or *Nage*. For simplicity, we use for the word (*Shite*) who *throws* or *takes down* the opponent, and then the one who will be thrown or taken down is the defender or opponent (*Uke*).

Black belts in Aikido wear a black belt and a very large skirt (mostly black color) named *Hakama*. In our book, the attacker (*Shite*) wears a *Hakama*; however, the defender (*Uke*) does not wear a *Hakama*. In the Yoshinkan Aikido style headed by Gozo Shioda, only the headmaster wears *Hakama*. The author of this book wears the *Hakama*.

10.7.5.2 Entering Throw (Irimi-nage: Tenkan) or Negative Motion

This technique is one of the basic throws that is taught to a beginner. One of the simplest ways to teach is the positive *Omote* or *Irimi*, facing directly the opponent and after blocking the attack the attacker to be thrown backward. This technique at the beginning of Figure 10.28a and 10.28b can be considered as "positive" (*Irimi*). When the opponent attacks, then the defender simply steps forward diagonally left, avoiding head-on collision and blocks the technique (Figure 10.28b).

Recall that in Aikido, good timing is the outmost in defense. This technique will be described as the "negative" (*Tenkan* or *Ura*) movement where the *Shite* always guides the attacker (*Uke*) in a circular fashion. The majority of the Aikido techniques end with circular movements. For the ease of understanding the attacker (*Uke*) techniques, we will describe mostly an attack by a strike.

Uke strikes with his right arm using a "knife hand" technique named *Shomen-uchi*. The *Uke* stands with his left leg in front (Figure 10.28a) and then he steps forward with his right leg at the time of striking the *Shite* (Figure 10.28b).

The *Shite* stands with his right leg forward. At the time of the attack, the *Shite* steps forward with his left leg diagonally to the left and outside of the *Uke*'s right shoulder. At the same time, with stepping, the *Shite* deflects the attack with the right edge of his palm (*Tegatana*) and guides down the *Uke*'s attacking arm (Figure 10.28b, see the arrow of the movement).

After blocking/deflecting the *Uke*'s attack, the blocking forearm of the *Shite* should use the lower part of his forearm, particularly the bone of the *ulna's styloid process* and his *carpal bones* of the hand, particularly the *pisiform* and *triquetrum* bones unification site and *lunate* bone. This place

FIGURE 10.28

has a little groove that should be used for a better guiding of the *Uke*'s attacking arm (see Figure 10.28c).

Note: In Figure 10.28a, the arrow of the *Shite* represents the left leg. The arrow of the *Uke* represents his right leg. The circular arrows in Figure 10.28b–d represents the circular motion of the *Shite* followed by the *Uke*. The *Shite*'s right leg executes the large circular motion (Figure 10.28b and 10.28c).

After the deflection and guiding of the *Uke*'s arm (Figure 10.28b), *Shite* simultaneously executes two actions: (1) Slides forward (if it will be necessary) a little bit more with his left leg. (2) *Shite* grabs *Uke*'s neck (nape part) with his left palm (the neck held between the thumb and the forefinger) pushing *Uke*'s body forward (Figure 10.28c). Many masters grab the collar of the *Uke* instead of the neck. The following movements that are executed circularly denote "negative" (*Tenkan*) *movements*. The next two movements will be: (1) *Shite* executes a large turning step backward with his right leg and at the same time pushing *Uke*'s neck more down (Figure 10.28c) and (2) *Shite* pulls *Uke*'s right arm also guiding toward backward and right (see Figure 10.28c). Follow the lines of the stepping actions seen in Figure 10.28a and 10.28b.

After this movement, the *Shite* does not have contact any longer with the *Uke*'s right forearm (Figure 10.28d). This figure also shows the beginning of the throw of the *Uke*. The *Shite* steps forward with his right leg (Figure 10.28e). The *Shite*'s lateral part of his right thigh can have a light contact with the *Uke*'s right thigh lateral part.

With the right leg's stepping motion, the *Shite* guides his right forearm (*radius side*) toward the *Uke*'s neck and with a circular motion toward his left throws the *Uke* down (Figure 10.28e and 10.28f). The last action should be executed energetically against the left side of the *Uke*'s neck (Figure 10.28g). The *Shite* holds the *Uke*'s neck for a long time, and releases his holding position on the Uke's neck only at the last moment (Figure 10.28g).

10.7.5.2.1 Observation of Physical Properties of the Irimi-nage (Negative) Technique From the beginning of the technique until the end of Figure 10.28d, the physical properties will be calculated under angular motion. There is an insignificant impulse at the time when the *Shite* will throw the opponent (*Uke*) (Figure 10.28e). Here, we have a short time and very light impact of linear movement. We leave this impact and impulse calculation for the reader.

At the beginning of this technique, the *Uke* has a short time of momentum when he attacks the *Shite*, but the thrower (*Shite*) will have a very large angular momentum. Velocity is important for the good timing of the *Shite*, who also produced a slight impulse for the technique.

If the timing is excellent then the momentum and impulse can be used very well. The *Uke*'s defense is difficult because his head will be pushed a little bit backwards and up. When anybody's head is pushed backwards, the following things can happen: (1) The *Uke* will lose more equilibrium when the head/neck is in a forced extension position. (2) The orientation for fighting (area) is very much lost.

The energy, work, or power of the attacker (*Shite*) will be calculated under the angular motion from Figure 10.28c and especially Figure 10.28d until Figure 10.28e. Calculating the energy and the work is pretty much the same. This technique from Figure 10.28c uses the angular kinetic energy, $KE_{ang} = 1/2\ \mathrm{kg} \cdot \mathrm{m}^2 \cdot \omega^2$. We will use the angular velocity (ω) *squared*. As an example, the *Shite* has 70 kg mass and his angular velocity is ω = rad/s. The *Shite* guides the *Uke* around about 180° or even more. We establish the 180° (3.14 rad). Then, 3.14/2.2 rad/s. Then the velocity (ω) = 1.42 rad/s. The 2.2 s is an estimated average velocity. We consider the radius (r) to be the total arm length of the *Uke* (excepting the hand) and this is about 0.60 m distance. This distance is from the *greater tubercle* of the *humerus* bone of the *Uke*'s right shoulder to the end of the wrist. The right elbow pit is the point where the attacker executes the pushing attack against the front part of the *Uke*'s neck. The right shoulder (greater tubercle) is the axis, the final $KE_{ang} = 1/2\ (70\ \mathrm{kg})(0.60\ r)^2(1.42\ \omega)^2 = 25.2$ J.

The *Shite* power will have units $P = \mathrm{N} \cdot \mathrm{m/s}$. The *Shite*'s momentum is relatively easy but the *Shite*'s impulse would be more difficult to establish because in this technique, the contact forces of the *Shite* and the rebound force of the *Uke* are very minimal and only exist theoretically.

Note: *In calculating the attacker (Shite's) KE_{ang}, the reader must keep in mind that the Shite uses the defender's (Uke's) arm for (r) radius and also that both Aikidoka do rotational motion*. The impulse (is very minimal, if any) can happen when the *Shite* throws the *Uke* by hitting with his right forearm (elbow pit) accidentally or deliberately the front part of the neck of the *Uke*.

10.7.5.3 Wrist Out-Turn Throw (Kote-gaeshi)

This technique is extremely efficient in self-defense and is also a spectacular one. Both Aikidoka stand with their right leg in front. The *Shite* wears the *Hakama*. The *Uke* with his right hand grabs the *Shite*'s right

wrist (Figure 10.29a). The *Shite* steps forward with his left leg outside of the *Uke*'s right leg (Figure 10.29b). The *Shite* with his left hand grabs the *Uke*'s attacking right wrist and at the same time uses the "*Kokyu-Ryoku*" maneuver (see Section 10.8.1) to liberate his right wrist from the grabbing position (Figure 10.29b and 10.29c). The *Shite* with the liberation maneuver "*Kokyu-Ryoku*" pulls forward the *Uke*'s right arm, making him to lose his balance (Figure 10.29c). To recover his balance *Uke* will be obligated to step forward with his left leg.

Note: In Figure 10.29a, the arrow indicates the *Shite*'s left leg stepping forward and outside of the *Uke*'s right leg. In Figure 10.29b, the *Shite*'s right leg describes a large backward movement. In Figure 10.29c, the small arrow indicates the *Kokyu-Ryoku* movement as a rotary motion. Figure 10.29d

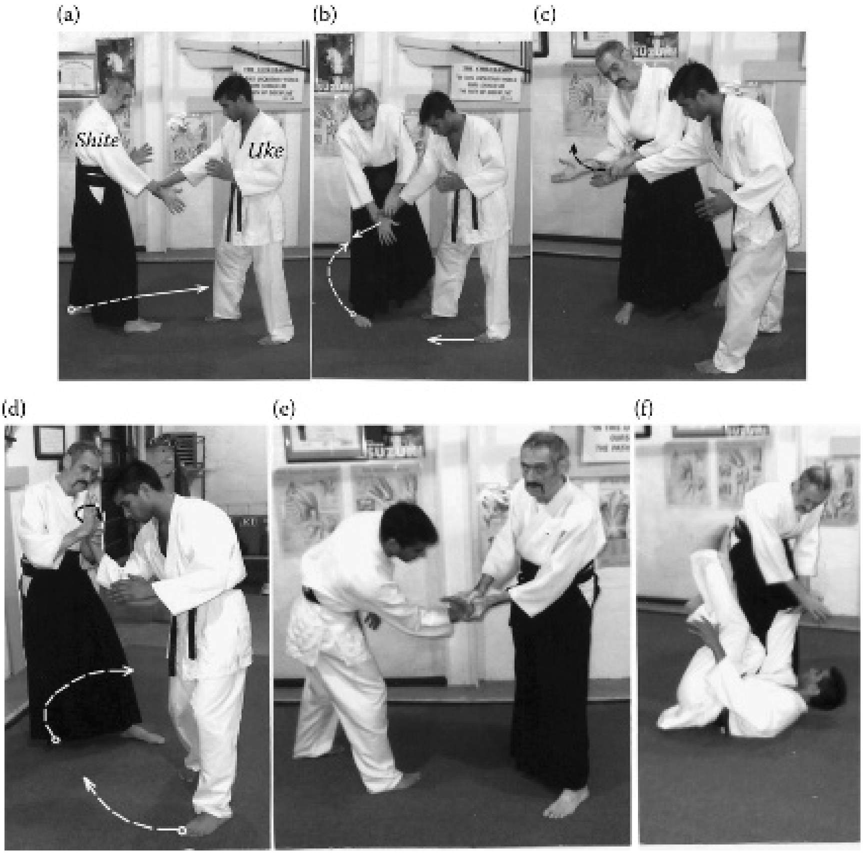


FIGURE 10.29

shows the *Shite*'s additional right leg backward turning movement. The intermittent line shows the right leg turning.

After the *Shite*'s right arm liberation, Figure 10.29c, the *Shite* holds the *Uke*'s right wrist firmly with his left palm (the thumb is on the back of the palm) and then sets his right open palm on the top of the *Uke*'s back of the palm, pressing down and backwards the palm of the *Uke* (Figure 10.29d). Meanwhile the *Shite* executes a large backward rotary step with his right leg pulling with him the *Uke* in a rotary way (Figure 10.29d).

The *Shite* will twist in continue to his left the *Uke*'s wrist (Figure 10.29e). *Uke* will fall down in a rotary way over his head resembling a tumbling movement. Figure 10.29f shows the final position of the *Uke* and the *Shite*. Usually, from this position, the *Shite* can manipulate the *Uke*'s wrist, immobilizing firmly without being necessary to get down near the *Uke* as usually is the case in jujutsu or in judo.

Note: There are at least 8–10 possibilities to maneuver the *Uke's* right fist before being thrown by the *Shite*.

10.7.5.3.1 Observation of Physical Properties During the *Kokyu-Ryoku* (hand liberation), there is strength involved especially at the beginner level. Observing Figure 10.29c and 10.29d, the *Shite* executes a short twisting and turning of the *Uke*'s wrist counterclockwise (CCW). This execution should occur extremely fast for the technique to be successful.

During the stepping motions of the *Shite* as a guiding force and the *Uke* as the follower, there are several physical properties to be observed: There is a rotary momentum of the *Shite* as well as the *Uke*. The rotary momentum occurs in a horizontal direction. Power is involved for the *Shite* ($P = \mathrm{N \cdot m/s}$). It is well known that if the *Uke*'s mass is very large, the velocity will be reduced accordingly. In this case, the *Shite* cannot develop sufficient power to overcome the *Uke*'s large mass.

If the *Shite*'s mass is large enough, he can develop an acceptable velocity for this technique. We should focus on the *Shite*'s angular momentum (L) because it deals with an active mass, velocity, energy, torque, and moment of inertia, which are related to this technique.

Recall that the *Uke* is only a follower even if he can exhibit the same physical qualities. The above-described technique does not specify how large is the turning (angular or radian displacement) of the *Uke*. For this case, we neglect the calculation of the horizontal angular momentum. Calculating the transverse *angular momentum* is more suited; in this case,

take a look at Figure 10.29e, where the *Uke starts to rotate through his transverse axis* (like a forward tumbling in the air).

Let us analyze the angular momentum (executed by the *Shite* over the *Uke*). The *Uke* and the *Shite* have 70 kg mass. The right shoulder of the *Uke* represents the rotational axis. By the *Shite*'s energetic action of turning and twisting the *Uke*'s right wrist, the *Shite*'s force is guided toward the *Uke*'s shoulder (axis of rotation). In this technique, the axis of rotation is not an axis; rather it is a point of rotation.

Note: When talking about the axis, we should take into consideration both shoulders; then we can talk about axis. However, the turning is not happening around a perfect axis line (such as both shoulders) because a lot depends on the *Shite*, how he maneuvers the twisting of the *Uke*'s hand during throwing and how the rotation can be over the sagittal axis by this maneuver.

Look again at Figure 10.29e and ask yourself where the radius of rotation is? It is from the right shoulder to the left shoulder of the *Uke*? Or it is from the right shoulder to the end of the feet of the *Uke* or even from the right shoulder to the end of the *Uke*'s right fist? The radius of rotation should be measured from the right shoulder to the end of the feet or can be measured from both shoulders' line to the end of the feet. Then the distance from both shoulders' line to the end of the feet will be the radius (r) = 1.40 m. The speed (an average) is approximately 1.2 s, and the radian is approximately 4.71. Then, angular momentum will be $L = m \cdot r^2 \cdot w$. Then, $L = (70\text{ kg})(1.40\text{ m})^2(4.71\text{ rad}/1.2\text{ s}) = 537.8\text{ kg} \cdot \text{m}^2/\text{s}$. The moment of inertia will be high because the CoM is not completely around the middle of the body that is rotated, but the body mass is prolonged with the legs of the *Uke*, which is very far from the axis of rotation. To calculate the torque, we have $T = \text{N} \cdot \text{m} = (70\text{ kg})(9.8\text{ m/s}^2)(1.40\text{ m}) = 960.4\text{ N} \cdot \text{m}$.

10.7.5.4 Rotary Throw (Kaiten-nage)

This technique can be executed in two ways. First, the *Shite* goes under the arm of the *Uke*, guiding the *Uke's* attacking arm upward and at the same time stepping under his arm. The name of this technique is "Inside Rotary Throw" (*Uchi-kaiten-nage*). The second option of the *Shite* is to remain outside of the *Uke*'s right shoulder. The execution of this technique is more difficult.

Here, we describe the first option *Uchi-kaiten-nage*. The *Shite* wears a Hakama and stands with his left leg forward. The *Uke* stands with his right leg forward and grabs the *Shite*'s left forearm at his wrist with his right hand (Figure 10.30a). The *Shite* prepares his defense and counterattacks by

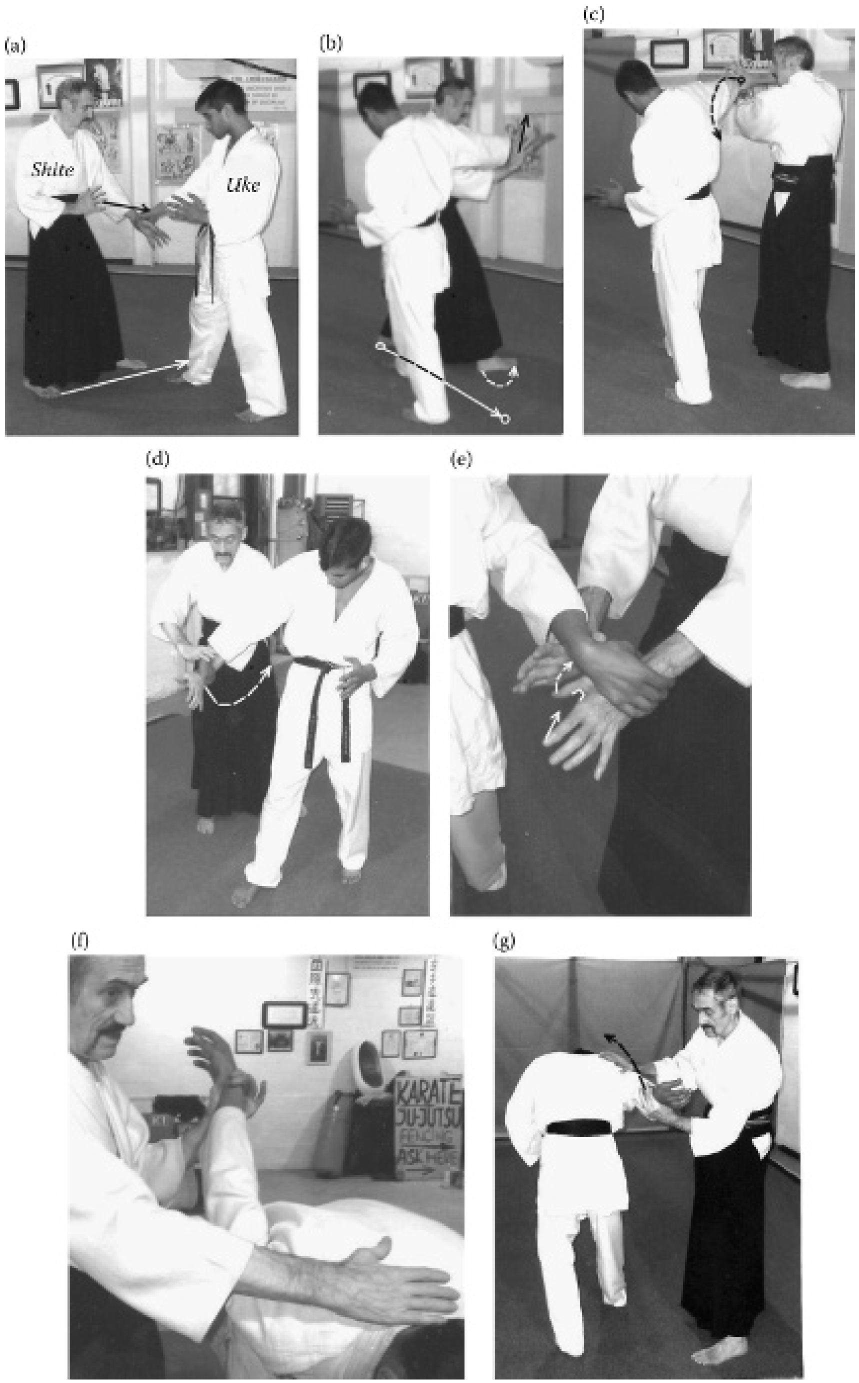


FIGURE 10.30

FIGURE 10.30 (Continued.)

stepping forward with his right leg outside of the *Uke*'s right lateral side. With his stepping forward, the *Shite* grabs the *Uke*'s right attacking arm at the wrist with his right hand (Figure 10.30b). During stepping under the *Uke*'s right arm, the *Shite* raises the *Uke*'s arm high (see the black arrow directed at the *Shite*'s right hand in Figure 10.30b).

So far the *Uke*'s arm described an angle of approximately 90° or more (compare the *Uke*'s right arm in Figure 10.30a when the *Uke*'s arm was approximately at 45° in front of his vertical line).

In Figure 10.30c, the *Uke*'s arm starts to descend and when his arm is descended it describes an angle of approximately 360° (Figure 10.30d). At this position, the *Shite* will use the *Kokyu-Ryoku* hand liberation maneuver and will grab *Uke*'s right wrist with his left palm. The white arrows indicate the grabbing points of the *Shite*'s left hand, between the first and the second metacarpal bones/joint (Figure 1.30e). Figure 10.30f shows the actual position of the Shite's left arm and right hand, which is directed against the *Uke*'s neck.

From a lower position, the *Shite*'s left arm (Figure 10.30d) will be raised high starting from Figure 10.30g. Figure 10.30h and 10.30i shows the actual rotary forward throwing of the *Uke*. It is extremely important before the throwing execution that the *Uke*'s elbow must be held in a complete extended position, which can be made by bending up the *Uke*'s wrist.

Note: The intermittent lines on the above figures represent the actions around the figures and not on the figures. Example Figure 10.30b shows the *Shite*'s left foot moving forward and his right foot are pivoting. See the

left foot of the *Shite* already moved forward which can be seen on Figure 10.30c. Also Figure 10.30c shows a rotary motion of the *Uke*'s right arm forward and not backward how seem to be. The arrow in Figure 10.30d shows the route (backward) of the *Uke*'s right arm. In Figure 10.30e, there are two small arrows that indicate the space between the thumb and the forefinger, which is supposed to grab the *Uke*'s right wrist. The arrows in Figure 10.30g and 10.30h clearly shows the *Uke*'s body forward rotation.

10.7.5.4.1 Observation of Physical Properties This technique's execution is totally different from the previous one. However, there is a lot of similarity with the hand liberation. Here, we cannot talk about *Uke*'s momentum from the viewpoint of physics. *Shite* starts with a linear momentum (p), where his velocity must be more important than his mass. From Figure 10.30f and 10.30g, the *Shite* can start a real angular momentum.

The axis can be considered the *Uke*'s two shoulders' line, but the rotation occurs mostly in the right shoulder. There is a force couple that can help the moment of inertia. The force couple is the shoulder and the neck of the *Uke*. These two points or, better said, areas work just like the bicycle driving wheel.

Comparing the *Uke*'s angular velocity (ω) and angular acceleration (α) of both techniques, the previous one (*Kote-gaeshi*) and the present one (*Kaiten-nage*), the angular velocity is much higher for *Kote-gaeshi*, yet the masses are the same and the axes are the same. The difference is the following: in *Kote-gaeshi*, the *Uke* is thrown with a smaller circle (understand the manipulation of the *Uke's* hand related to *Shite's* hand); meanwhile, executing the *Kaiten-nage*, the *Uke* describes a large circle, not only circular but most importantly like an elliptical (egg-shaped) path, which prolongs the angular velocity.

The moment of inertia $(I) = m \cdot r^2$, where (r) from the axis (both shoulder lines) to the end of the legs is 1.40 m. In this case, $(I) = (70\ \text{kg})(1.4\ \text{m})^2 = 137.2\ \text{kg}\cdot\text{m}^2$. The rotation of the arm that will be pushed will drive the body into forward rotation. We use the extended arm as a starting point for the forward rotation. We should count the forward rotation of the body only from the position when the *Shite* leaves the *Uke*'s right arm, which is shown in Figure 10.30h; however, when the *Uke*'s right arm reached at the vertical point, or a little bit passed, the rotation can be calculated for the body. For the moment of inertia equation, we chose the basic equation for the hoop about the symmetry axis.

Uke's back is now approximately in a prone position (Figure 10.30h). When the Uke's body rotates forward, at the time of landing on the mat, it will be in a supine position and has moved 180°, which is 3.14 rad.

In Figure 10.30h, the *Uke*'s arm approaches the vertical line and this is approximately the point (vertical or a little bit over the vertical line) when the *Shite* releases the *Uke*'s arm completely and the *Uke* is rolling forward. In this case, our calculation for the angular velocity of the *Uke*'s body ω = rad/s = 3.14 rad/1.25 s, or $\omega = 2.51$ rad/s. The final calculation for $KE_{ang} = 1/2[(I)\ 137.2][(\omega)\ 2.51]^2 = KE_{ang} = 432.18$ J. The 1.25 s is an average velocity.

Note: Actually the 1.25 s can be more because of the oval rotation. Recall that the *Uke* executes a circle when he rotates, but this rotation is more an oval-shaped rotation. If the *Uke* would do exactly a correct circle rotation, the speed would be less than a second. We cannot debate at this time what percentage is the oval-shaped rotation, so we took an approximation for the correct circle rotation. Analyzing Figure 10.30h, the readers should keep in mind that the real rotation of the body starts when the *Uke*'s right arm passes over the vertical line.

Calculating the rotational power of the *Uke*, we will have $P = T \cdot \omega$. From here, it is easy to calculate the rotational power of the *Uke*. We will not use this calculation. This is left to the reader.

10.7.5.5 Four-Side Throw (Shiho-nage)

This technique is very sophisticated probably for any martial artist with a different martial art background. In order to execute efficiently, the Aikidoka must be very precise getting the correct hand (wrist) grabbing technique.

Facing each other, the *Shite* is with the *Hakama* and stands with his left leg forward. The *Uke* stands with his right leg forward. The *Uke* strikes with a right hand over the head of the *Shite* with a *Shomen-uchi*, executed with the hand blade. The *Shite* blocks the attack with his left hand blade or with the lower part of the forearm (Figure 10.31a). The *Shite* instantaneously guides down the *Uke*'s arm with a rotary movement, and then grabs the *Uke*'s wrist with both hands.

The right hand grabbing must be more firm and forceful than the left hand (Figure 10.31b). At this time, the *Shite*'s left foot is outside of the *Uke*'s right foot. The *Shite* pivot on his left foot turns backward and to the right with his right foot (Figure 10.31c). During turning with his right foot, the *Shite* (with his right hand) must turn over and backward forcefully the

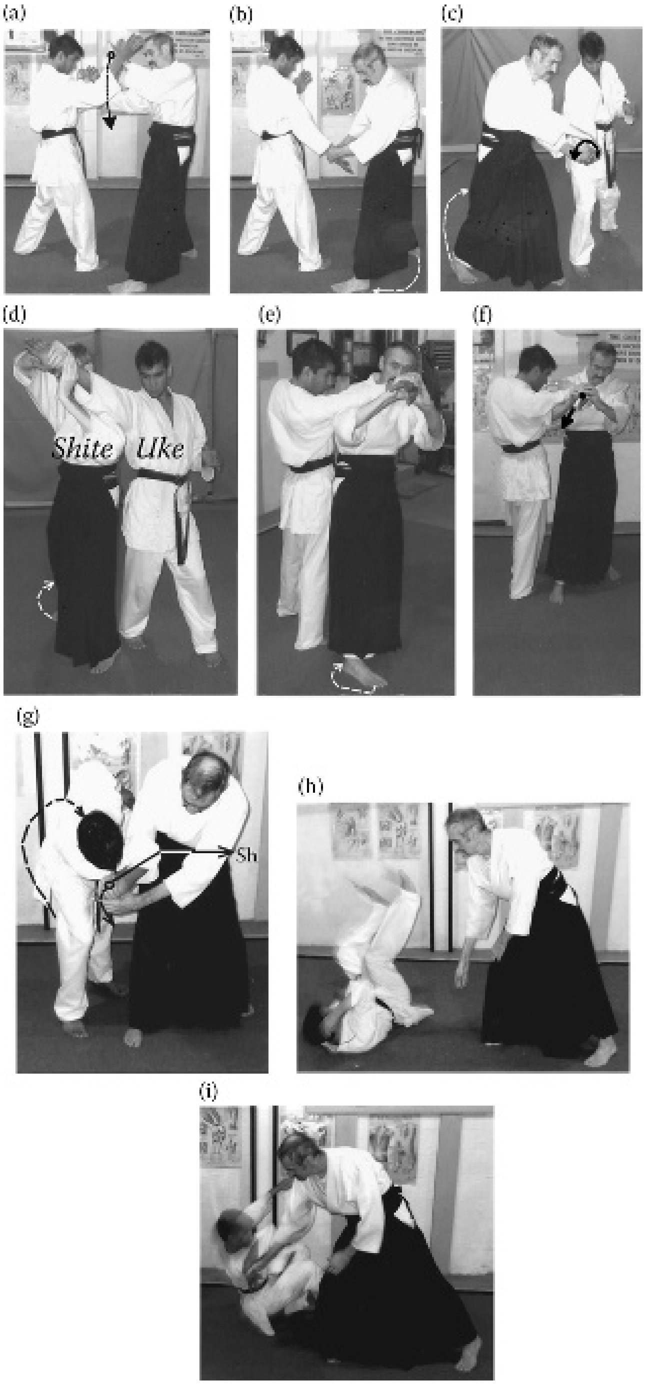


FIGURE 10.31

Uke's hand assuring a very firm grip (see Figure 10.31c—the *Shite*'s hand is on the top of the *Uke*'s hand). Follow the arrow that indicates the turning direction.

The *Shite* continues to turn with his right leg until he is side by side with the *Uke*'s body (Figure 10.31d). During this continuous turning, the *Shite* extends the *Uke*'s arm. When the *Shite* completes his turning, he will be with his right side against the *Uke*'s right side of his body (Figure 10.31e and 10.31f). At this time, the *Shite* must close the little gap between his right upper arm and the *Uke*'s shoulder. Figure 10.31e shows clearly that the *Shite*'s upper arm holds the *Uke*'s upper arm. When the gap is closed, because the *Shite* pulls the *Uke*'s body closer to him, the *Shite*'s forearm will hold the *Uke*'s upper arm and his bent right wrist (Figure 10.3f).

Following the next step from Figure 10.31f is the throwing process. Here are two possibilities to throw the *Uke:* starting from Figure 10.31f, the *Shite* will take a large step forward and by holding the *Uke*'s left hand the *Shite* guides down the *Uke* to immobilize him (Figure 10.31i).

The second possibility from Figure 10.31f is that the *Shite* simply throws forward the *Uke* (Figure 10.31g and 10.31h).

Observation about the figures: In Figure 10.31c (the middle of the figure), the black semicircular arrow shows the *Shite*'s action turning and twisting the *Uke*'s palm upward and then downward. In Figure 10.31f, the arrow shows the *Shite*'s down pushing action on top of the *Uke*'s palm. In Figure 10.31g, the large semicircular arrow shows the direction of the *Uke*'s body rotation forward. The letters "Sh" represents the *Shite*'s right palm (see the tiny circle representing the top of the palm). Under the tiny circle, the round arrow represents the turning of the *Uke*'s palm.

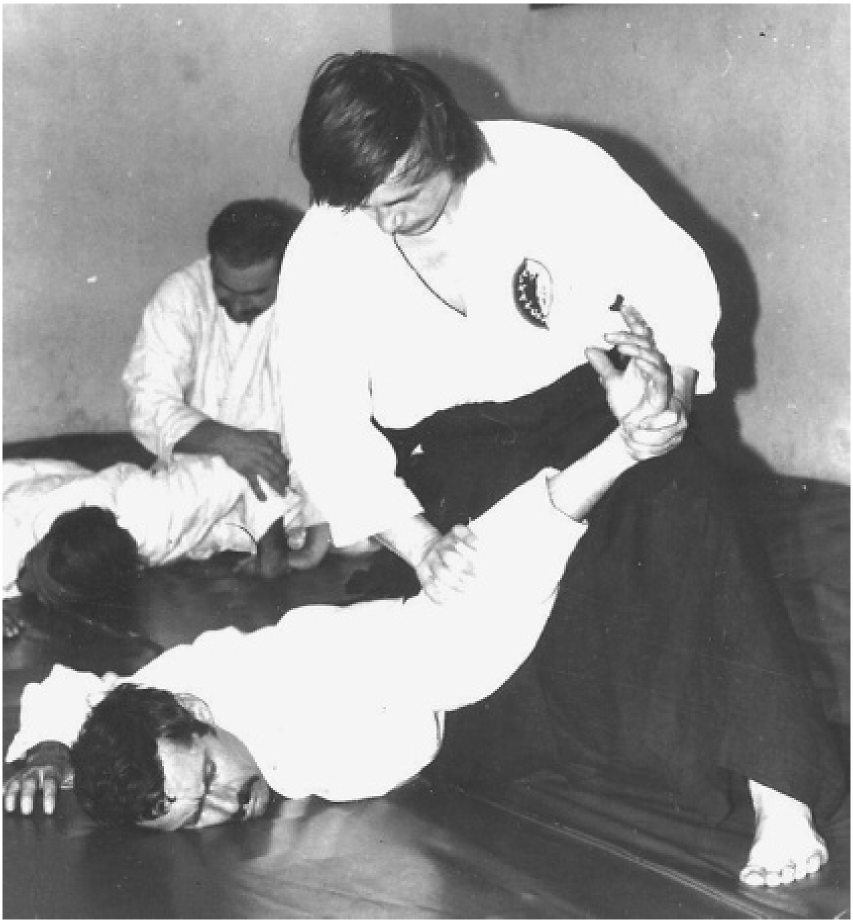
10.7.5.5.1 Observation of Physical Properties The *Uke* only has a short step with his left leg, which is due to the *Shite*'s action of turning, twisting, and pulling the *Uke* to a throwing position. *Uke* will remain in this position till the throwing starts. From here, the *Uke* has an angular motion that is guided by the *Shite*'s throwing action.

Uke offers a lever to *Shite* before throwing. This lever is the *Uke*'s forearm. Analyzing all the components of this lever, the axis will be represented by the *Uke*'s elbow. The resistance moment arm (RA) is represented by the weight of the *Uke*'s right hand and gravity. This RA works downward.

The force arm (FA) is represented by the *Shite*'s upper part of his forearm, particularly his elbow pit through to 1/4th of the forearm, which elevates the *Uke*'s upper arm. In this way, the FA works upward.

During the forward rotation of the *Uke*, the moment of inertia is large because the *Uke*'s both legs are widely spread apart and they are also far from the center of rotation (axis). If the *Shite* decides not to throw the *Uke* and to use the take-down technique (Figure 10.31i), then there will be no moment of inertia because the take-down movement eliminates any rotational motion such as torque, angular power, and so on. Figure 10.31h represents a direct throw by the *Shite*. Consulting Figure 10.31i, there is an immediate take-down and immobilization of the *Uke* on the mats.

10.8 AIKIDO IMMOBILIZATION TECHNIQUES (*KATAME WAZA*)



Arm pin (*Ude-osae*)—*IKKYO*. Technique executed against the author by one of his students.

In Aikido or in any martial arts, the defender must know how to defend himself against any kind of attack, such as kicking, striking, punching, and grabbing, and of course an expert should know how to defend himself against weapons such as knife, baton, and sword, and even against a pistol and so on.

In Aikido, for some reason, the strikes with an arm are executed against a defender with large circular movements. These movements are more

visible than punches and kicks executed by a karateka or by a boxer; their punches are executed more in straight line fashions that are much faster than the Aikido strikes.

A defender (*Uke*) must be knowledgeable against any type of grabbing (grabbing one arm, two arms, or collar) and how to defend oneself. Also, the defender must decide what kind of counterattack to execute against the attacker (to use a throwing or immobilization technique). An important part of any Aikido training is the hand grabbing liberation "hand turning" (*Te-sabaki*) technique, which is executed by turning the hand blade (*Tegatana*) in determined specific ways. The hand blade includes the tip of the little finger to the junction of the hand and wrist, most precisely at the *tuberosity of the pisiform bone* (*carpals*) of the hand.

10.8.1 Arm Grabbing Liberation (*Kokyu-ryoku*)

According to Aikido experts, the liberation of a forearm from a hand grabbing happens by the so-called "breathe power" in Japanese (*Kokyu-ryoku*). What exactly is the meaning of "breathe power"? It is a kind of breathing force, which named *Ki* in Japanese or *Chi* in Chinese. This breathing force is a key essence, directing your reservoir of breath that is found in the upper portion of the diaphragm, which is in fact also the lower portion of the thorax.

By doing certain movements (always circular) with the hand blade (*Tegatana*), the defender has a great chance to liberate his wrists from any kind of forceful grabbing. For many Westerners, this kind of explanation is esoteric. In this book, we will not describe the way the *Ki* is working; however, an explanation on the *Tegatana* maneuvering technique by mechanical means will be described here.

There are two modalities: (1) when the attacker grabs, for example, the defender's right wrist with his left palm, the defender first twists then rotates (Figure 10.32a) his right palm in such way to direct the edge of his palm over the attacker's forearm. (2) With the same position, the defender twists his wrist again, and then, as he lifts up the edge (all the finger tips together) of his palm, at the same time he lowers his elbow. With this force couple, it is much easier to liberate his wrist from the grabbing position.

An additional explanation needs to be described about the *Tegatana*. Top Aikido experts have different ways to hold their hand blade *Tegatana*. One way during maneuvering (twisting) your wrist with the guiding process of the *Tegatana* is to hold your fingers completely united together, eventually leaving your thumb far away from your palm.

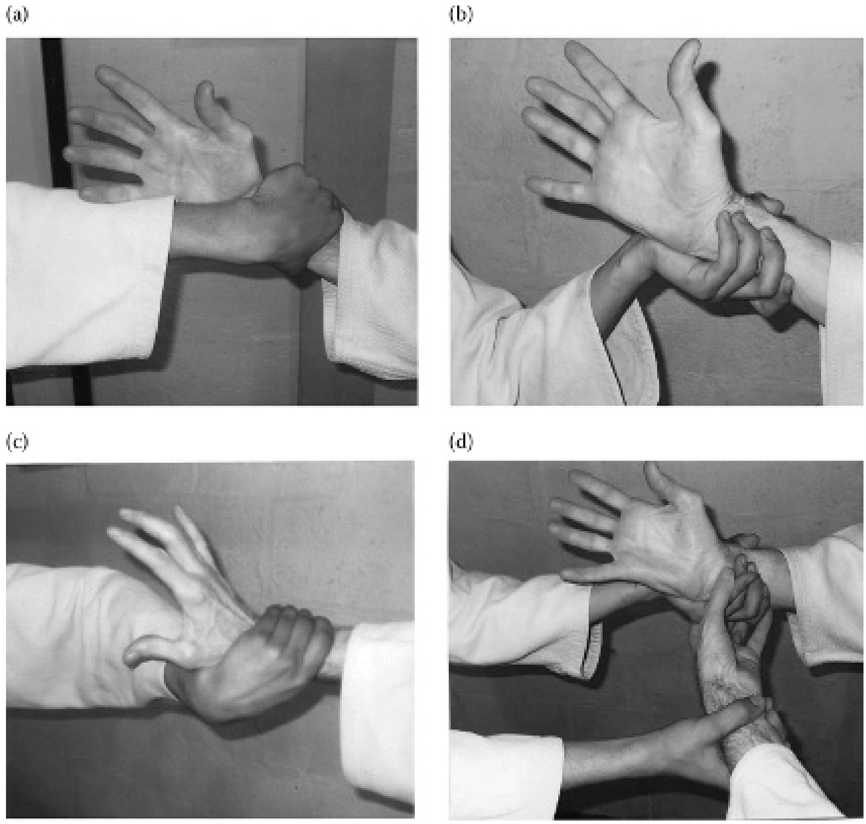


FIGURE 10.32

Another way, and this is the most correct one, is to hold apart all your fingers forcefully. The reason for this is that if the fingers are separated from each other, particularly the pinkie, then when the hand blade is in "flexed position," three important muscles *flexor carpi ulnaris*, *flexor digiti minimi*, and *abductor digiti minimi* can work together by increasing the muscular contraction at this part of the hand blade, making it possible for the liberation of the wrist.

If the fingers are held together like a spear, it has less chance to get liberated from a grabbing position. In this case the muscles are in neutral working position. Figure 10.32a–d demonstrates a few positions of the hand blade (*Tegatana*) with the wrist in liberated position.

Recall that for any throwing or immobilization technique, first, the defender must liberate oneself from the grabbing position held by the attacker and then he can choose to throw or immobilize his attacker. More

variety of liberation from grabbing will be described in Sections 12.1.1 through 12.1.4.

Figure 10.32a–d shows the *Tegatana* techniques. Figure 10.33a–f shows the *Tegatana* maneuvers by liberating from a grabbed position and continuing a counteraction to regrab the attacker's wrist.

Figure 10.32b shows the liberation of the wrist executed with the right hand blade (*Tegatana*) on the top and at the same time shows the grabbing maneuver of the attacker's fingers with the left hand (fingers) of the defender (lower position) (Figure 10.32d).

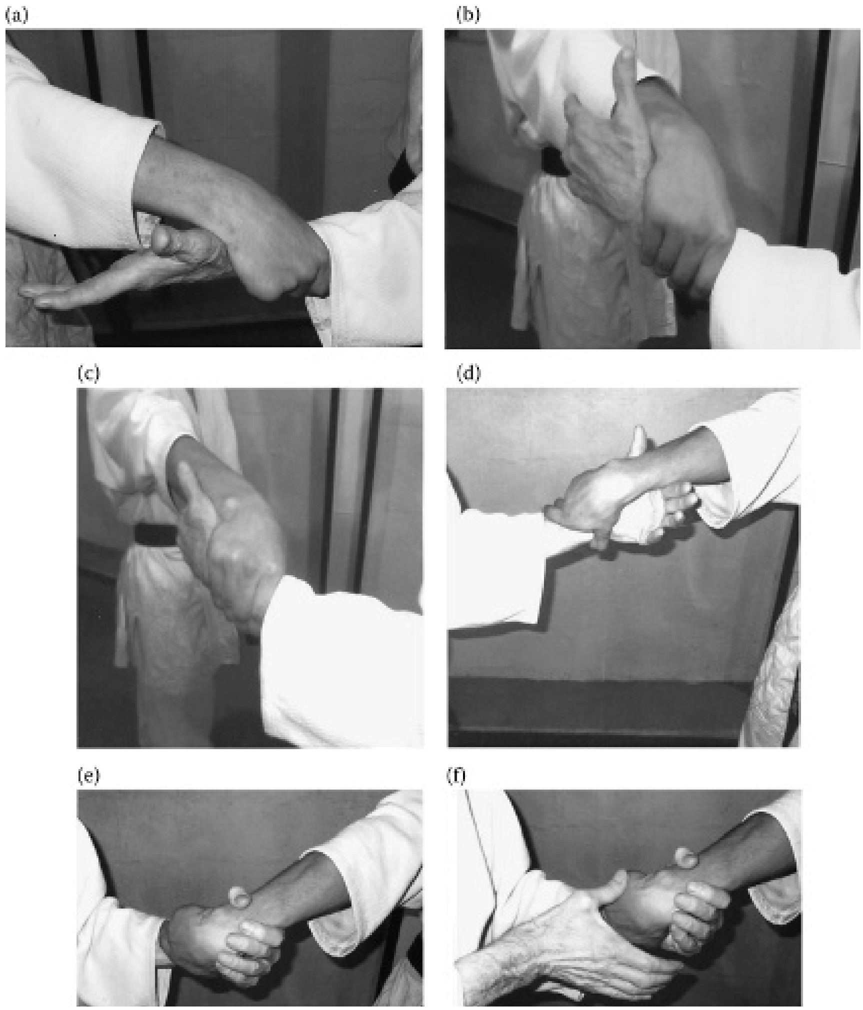


FIGURE 10.33 Arm grabbing liberation (*Kokyu-ryoku*).

In Figure 10.33a, the defender executes a very simple and easy *Tegatana* maneuver. The defender executes the maneuver with his left hand. In Figure 10.33b, the defender's left hand twists more toward the attacker's forearm. Figure 10.33c shows the defender's left palm by touching the attacker's right forearm.

For a better understanding of the maneuver, the defender's left forearm is now on the left side of the figure and shows that the defender is now reaching to grab the attacker's right wrist (Figure 10.33d). Figure 10.33e shows the actual regrabbing of the attacker's right wrist.

Figure 10.33f shows the possibility of the defender to counterattack by grabbing not only the attacker's right wrist but also the attacker's back of the palm. From here, the defender has endless possibilities to execute a take-down for immobilization or throwing techniques.

10.8.2 Biomechanical Analysis of the Techniques

In Aikido, there are four basic take-down techniques that are used to guide down or throw the opponent and then immobilize him. These take-down techniques can also be finalized as a throwing technique. In Aikido, especially in Aikijujutsu, there are endless technical attacks and defenses. Recall that in Akido the attacker's name is *Uke*, who later on will be thrown or taken down by the defender, the *Shite*. Here are the four techniques related to hand positions:

1. First option, arm pin (*Ude-osae*) or *Ikkyo*.
2. Second option, wrist in-turn (*Kote-mawashi*) or *Nikyo*.
3. Third option, wrist twist (*Kote-hineri*) or *Sankyo*.
4. Fourth option, wrist pin (*Tekubi-osae*) or *Yonkyo*.

10.8.2.1 Arm Pin (Ude-osae) or Ikkyo

Figure 10.34a–f shows the positive execution and Figure 10.35a and 10.35b shows the negative execution. Recall that the person who grabs or hits is named the *Uke*. The person who defends himself by throwing the *Uke* or by immobilizing is named the *Shite*. This technique of immobilization executed by the *Shite* should be directed against the *Uke*'s elbow. The arm of the *Uke* must be extended completely at the site of the elbow.

The immobilization can be done in a standing position; however, it cannot be held for a long time because the *Uke* has the chance to pull or push

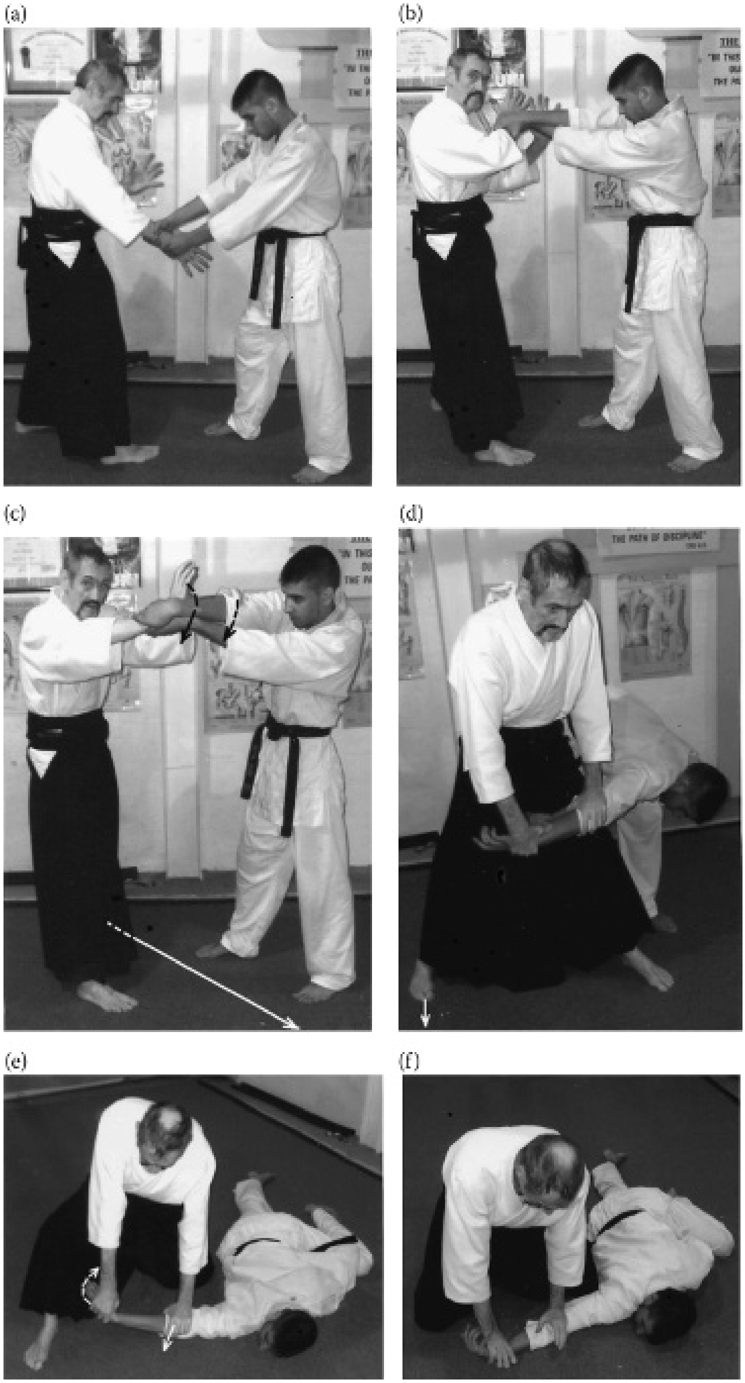


FIGURE 10.34

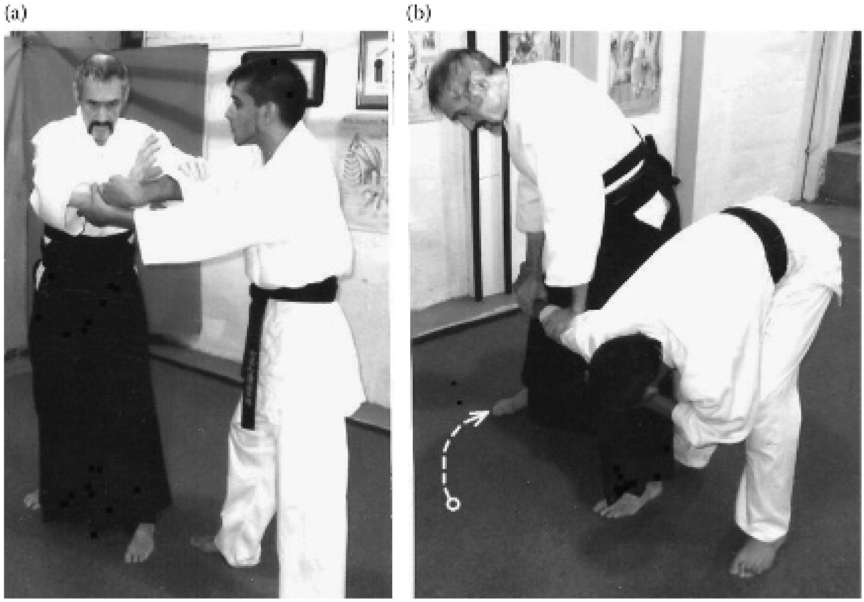


FIGURE 10.35 *Ude-osae*, negative technique.

his extended arm away from the *Shite*. That is why the *Shite* must guide down the *Uke* on the mat and immobilize him.

The person with the *Hakama* (large skirt) is the defender (*Shite*); Figure 10.34d shows the preliminary immobilization position (see the *Uke's* extended arm). The following figures will show an execution of the arm-pin or *Ikkyo* positive technique.

Description of the arm-pin (positive) technique execution: Both Aikidoka stand with their right leg forward. The *Uke* grabs the *Shite*'s right arm at the wrist with both arms (see Figure 10.34a). The *Shite* must execute the *Kokyu-ryoku/Tegatana* maneuver (Figure 10.34b and 10.34c). Then, in order to execute the *Ikkyo* positive technique, the *Shite* will apply his left palm or the forearm on the *Uke*'s elbow, pressing down and at the same time steps forward with his left leg in front of the *Uke* and presses down the *Uke's* extended right arm continuously (Figure 10.34d).

This position of Figure 10.34d *is considered to be the key of the Ikkyo technique*. The *Shite*, besides pressing the *Uke*'s right arm, must also pull the *Uke*'s arm continuously toward his right (Figure 10.34e). The final position of the immobilization can be seen in Figure 10.34f.

Description of the arm-pin (negative) technique execution: The execution is similar to Figure 10.34b and 10.34c; however, the *Shite* will stay with

his left leg forward (see Figure 10.35a). From this position, the *Shite* turns with his right leg to his right and backward, pulling the *Uke* with him (Figure 10.35b), and then presses down the *Uke*'s arm exactly as before in the positive technique.

From now on, the *Shite* must follow the previous execution movements to immobilize the *Uke* on the ground. It is extremely important for the *Shite* to pull the *Uke's* extended arm all the time. If the arm is not extended and more importantly is not pulled, then the *Uke* can roll forward and escape.

The *Uke* has several options to defend himself: At the very beginning of the technique when the *Shite* applies his left palm on the *Uke*'s right elbow, he must flex his right arm and push the arm forward, holding the flexed position.

After getting close to the *Shite*, the *Uke* can grab the *Shite*'s attacking arm or grab the *Shite*'s collar or initiate any self-defense technique, especially from judo. When the *Shite* manages to keep the *Uke*'s arm extended, the *Uke* must push his extended arm more laterally, and right then try to roll forward to escape.

Note: In Figure 10.34b and 10.34c, the reader can observe that the *Shite* lifts up the arms of the *Uke*, which is a prerequisite for the successful execution of the *Kokyu-ryoku* maneuver. This detail is extremely important as has been explained earlier.

10.8.2.1.1 Observation of Physical Properties In both positive and negative execution, the *Kokyu-ryoku* (hand twisting maneuver) is the primary movement for assuring the *Shite*'s left palm or forearm position on the *Uke*'s elbow. Applying the positive technique, the *Shite* will have a large momentum using his mass and velocity equally. The *Shite*'s momentum will be linear until the moment when the *Shite* applies the final pressure against the *Uke*'s elbow to push down and ultimately fix him on the ground. Kinetic energy will be crucial for the successful immobilization of the *Uke* on the mats.

In the negative execution of this technique, the *Shite* has a very large rotary momentum immediately after the *Uke*'s elbow has been assured for pushing down. The *Shite* in this technique must have an excellent equilibrium because his right leg could unbalance the *Shite* during a large turning and because the *Shite*'s body, and not only his leg, must turn to his right (Figure 10.35b). The *Shite*'s body during his turning describes an angle of approximately 45–80°.

The more the turning, the more difficult it is for the *Shite*; however, the advantage is to make the *Uke* lose his balance almost completely. We can calculate $KE_{ang} = 1/2\ (m \cdot r^2)\omega^2$. Angular momentum $(L) = \mathrm{kg} \cdot \mathrm{m}^2/\mathrm{s}$.

10.8.2.2 Wrist In-Turn (Kote-mawashi) or Nikyo

We just showed how the technique should be executed; however, we will not describe this technique later on. The basic execution of the *Shite* is that he must turn the *Uke*'s hand to the right (in case if the *Uke* attacks/grabs with his right arm) and the elbow of the *Uke*'s must be turned to the left of the *Shite* (Figure 10.36a and 10.36b).

These two combined forces deliver an excruciating pain and the *Uke* will go down. When the *Uke* starts to go down and usually will touch the mat with his left palm (in our case), then the *Shite* executes a finalization against the *Uke*'s wrist, elbow, or even his fingers. In Aikijujutsu, it is allowed to attack even the fingers, like turning, twisting, and pressing against the normal anatomical positions.

10.8.2.3 Wrist Twist (Kote-hineri) or Sankyo

This technique is named *Uchi-kaiten Sankyo*, which indicates that the *Shite* will maneuver the *Uke*'s hand by stepping under the *Uke*'s arm. From the beginning of this technique to the end, the opponent's hand (fist or open palm) should be twisted all the time. It is an extremely effective technique

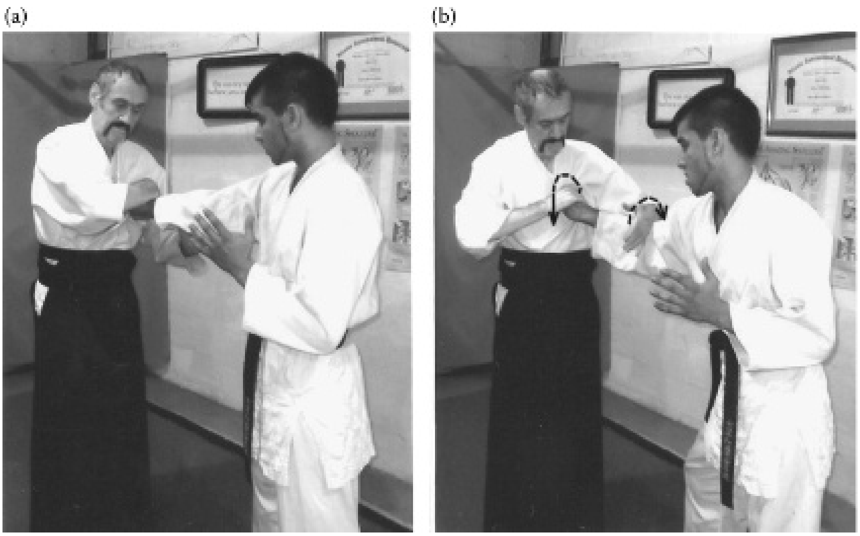


FIGURE 10.36

and can relatively be easily executed, with the *Shite* guiding the *Uke*'s arm (e.g., right arm) behind his back.

The *Uke* stands with his right leg in front and with his right arm grabs the *Shite*'s left arm. The *Shite* stands with his left leg in front (Figure 10.37a). The *Shite* immediately executes a *Kokyuryoku* maneuver with his left palm grabbing the *Uke*'s wrist on the palm side. At the same time, *Shite* grabs the back of *Uke*'s right palm (Figure 10.37a).

The *Shite* at this time has a firm grip on *Uke*'s left wrist. The *Shite* shortly steps with his left leg, then steps forward deeply with the right leg (Figure 10.37b), passing under *Uke*'s right arm pits and raises up the *Uke*'s right arm (Figure 10.37c). Figure 10.37d, shows the *Shite* position after the ducking.

Figure 10.37d also shows the *Shite*'s left arm holding the *Uke*'s right arm high. From this position, the *Shite* guides down the *Uke*'s right arm and then the *Shite* steps forward with his right leg (Figure 10.37d—see the intermittent line) and turns his body CCW to face the *Uke*. The *Shite* moves his right leg backward and holds the *Uke*'s right opened palm only with his left palm (Figure 10.37e).

Figure 10.37e (1) and 10.37e (2) shows the *Shite*'s palm position on the *Uke*'s hand. The black and white arrows indicate the twisting position of the *Shite*. Figure 10.37e (1) indicates the Aikido's *key position of the Sankyo technique*. Figure 10.37e (2) shows the Aikijujutsu's *key position of the Sankyo technique*. The white arrow in Figure 10.37e (2) shows that the pinkie of the defender that is pressed down and backward to create more pain for the assailant. The *Shite* moves his right leg backward one more time, holding in the mean time the *Uke*'s right palm and setting his right palm on the *Uke*'s elbow pressing it downward (Figure 10.37f). By a double action of both the *Shite*'s arms, by pressing the *Uke*'s elbow with the right palm and pulling/twisting the *Uke*'s arm more forward, the *Uke* will be on his stomach (Figure 10.37g).

The *Shite* will kneel down on his right knee (Figure 10.37h) and execute the final immobilization of the *Uke* (Figure 10.37i). Figure 10.37i shows the typical immobilization of Aikido; however, from this position, Aikijujutsu practitioners can execute many diverse finalizations.

10.8.2.3.1 Observation of Physical Properties In this technique, there are many different physical properties involved, such as speed, which is guided by the skill of the *Shite*, momentum, kinetic energy, power, and so on. The most important physical property is the momentum (p) and the technical skill of the attacker (*Shite*). If the momentum is slow, the

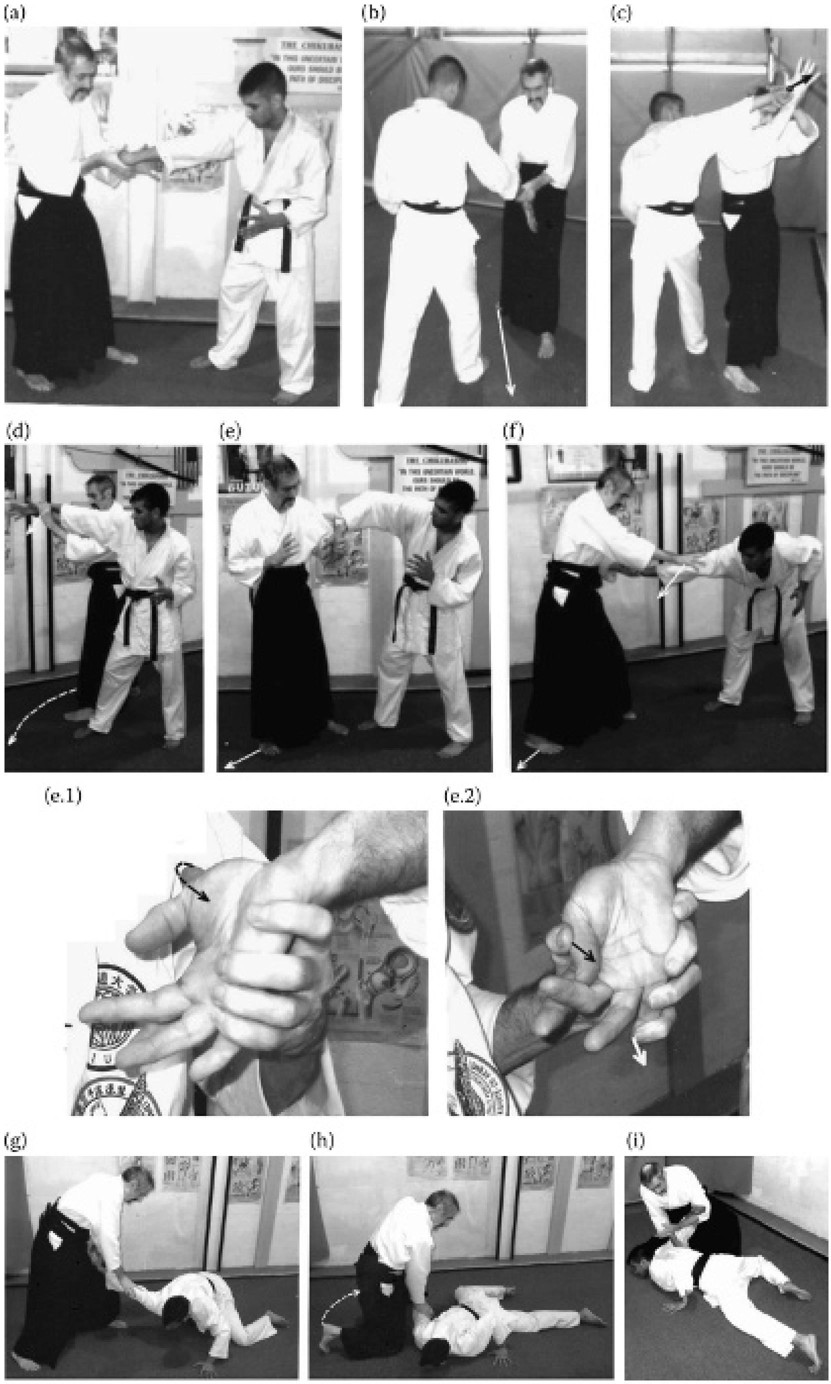


FIGURE 10.37

technical skill cannot be achieved because maneuvering the *Uke*'s fist or palm cannot be achieved. The *Uke* can withdraw, push, or even twist his wrist for liberation.

Recall that this technique can be executed relatively easily, by the permanent twisting execution of the *Shite*; however, the twisting maneuver will be difficult if the *Uke* holds his fist firmly closed. Calculating any physical properties can be extremely difficult because the distances of the moving arms (of the *Shite* or the *Uke*) or the distances of the moving leg of the *Shite* are relatively very short. These short distances change in almost seconds.

10.8.2.4 Wrist Pin (Tekubi-osae) or Yonkyo

More time is required to learn this technique than any other techniques in Aikido. The *Shite*'s action against the *Uke*'s wrist requires good anatomical knowledge and precision to press at the radial artery. Basically, the point of pressing should occur from the wrist approximately 5 cm or 2 inches toward the elbow.

It is absolutely recommended not to exceed more than 5–6 repetitions with absolute strength per session of training class because pressing the radial artery will constrict the diameter of the artery (stenosis), which can make the person to pass out.

The *Uke* stands forward with his right leg grabbing the *Shite*'s left wrist. The *Shite* as usual wears the large skirt (*Hakama*) (Figure 10.38a). This position is identical with the first position of the previous technique (Figure 10.37a). The *Shite* as usual executes a *Kokyu-ryoku* technique to make his next step of applying the *Yonkyo* technique easier.

In Figure 10.38b, the *Shite* applies his right palm on the back of the palm of the *Uke*. Until now, this technique is almost the same as the previous one (Figure 10.37a). Instead of twisting the *Uke*'s palm, the *Shite* applies a *Kyusho* technique against the *radial artery*, not on the radial nerve that lies much deeper under the radial artery. The *Shite* still must hold firmly the *Uke*'s back of the palm. *The Uke's forearm should be held with the palm side toward the ground.*

The *Shite* opens apart his left hand thumb and the index finger, then with the palm side of the second metacarpal head applies the pressure (*Kyusho*) against the radial artery (5 cm from the wrist).

Note: Figure 10.39a shows the exact the location (pressure point noted with a circle and an arrow), which indicates upward pressing against the *Uke*'s forearm. Figure 10.39b shows the *Shite*'s arm by pressing upward the

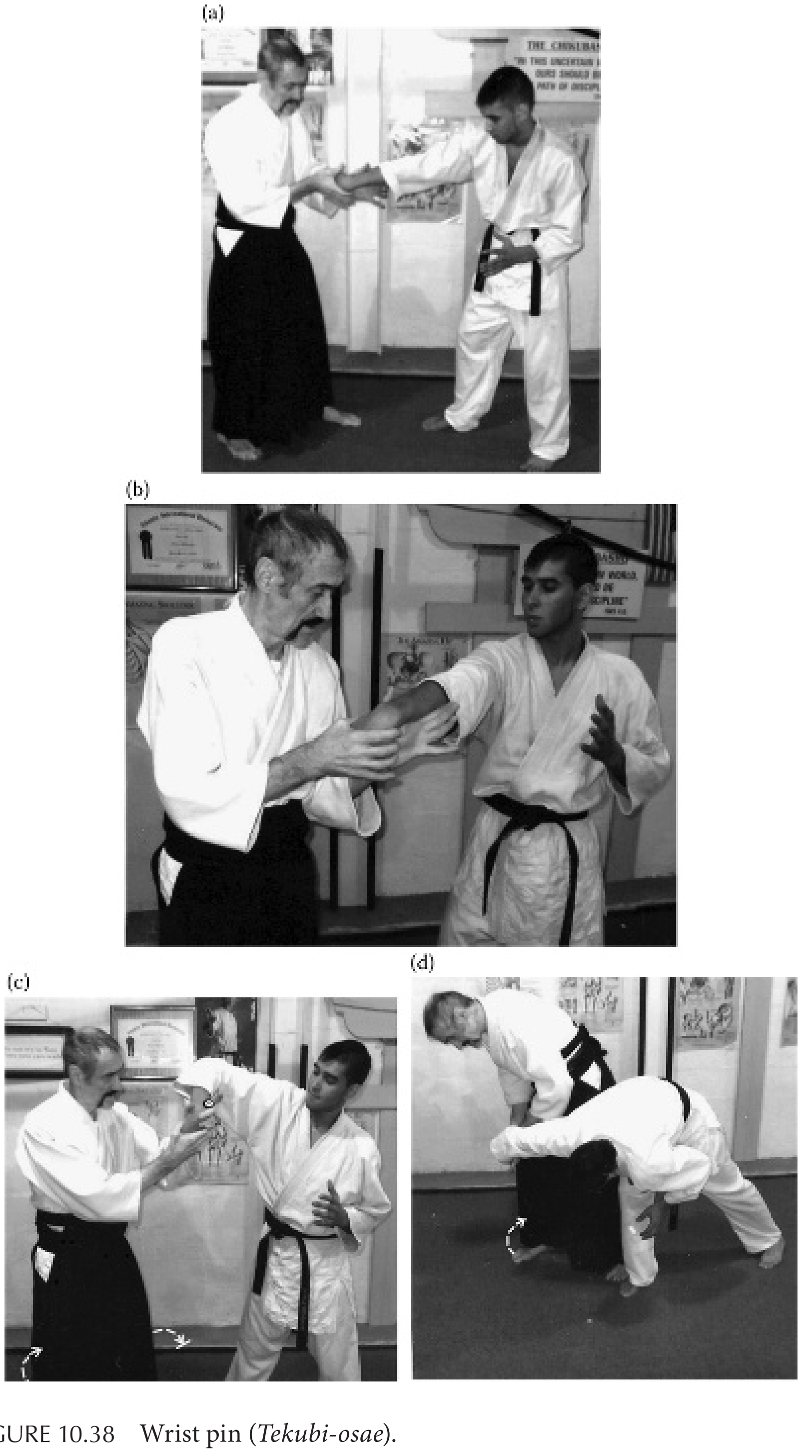


FIGURE 10.38 Wrist pin (*Tekubi-osae*).

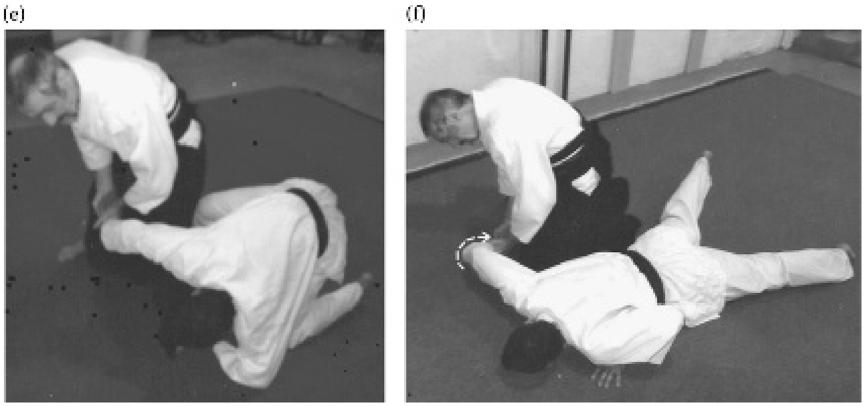


FIGURE 10.38 (Continued.)

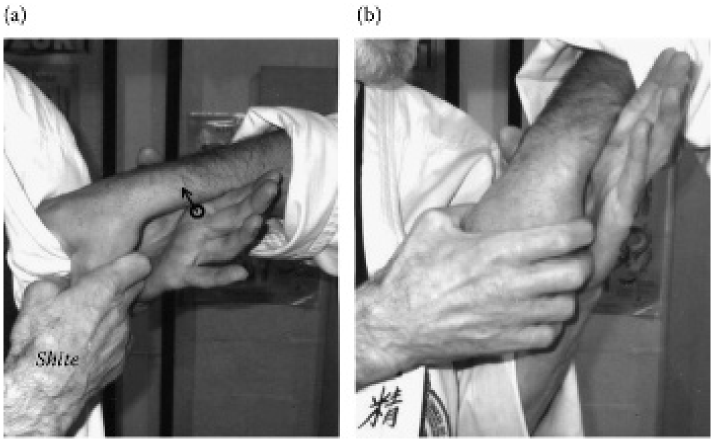


FIGURE 10.39 *Kyusho* (pressure point) technique against the radial artery.

Uke's right forearm with his left hand and downward holding and pressing the *Uke*'s back of the palm. In Figure 10.39c, there is a tiny black/white spot (circle) that indicates the point where it should be pressed up the *Uke*'s forearm.

During the time with the applied upward pressure against the wrist, there are additional important maneuvers to be performed in order to be successful with this technique:

1. When the pressure is applied upward against the *radial artery*, the back of the palm must be pressed downward.

2. Do not close both fingers of the attacking hand (tips of the thumb and forefinger) in order to have a strong holding on the wrist. In this case, if the two fingers are touching or almost touching each other's tips, the pressure (*Kyusho*) will not be efficient.

3. At the beginning of applying the pressure, keep the attacked hand at a higher position than his shoulder.

Once the attacking position (pressure) is assured (Figure 10.38c), the *Shite* will turn his right leg toward his right and at the same time drop the high holding position of the *Uke*'s hand (Figure 10.38d), forcing the *Uke* to go down to the ground (Figure 10.38e). Finally, the *Uke* will be immobilized.

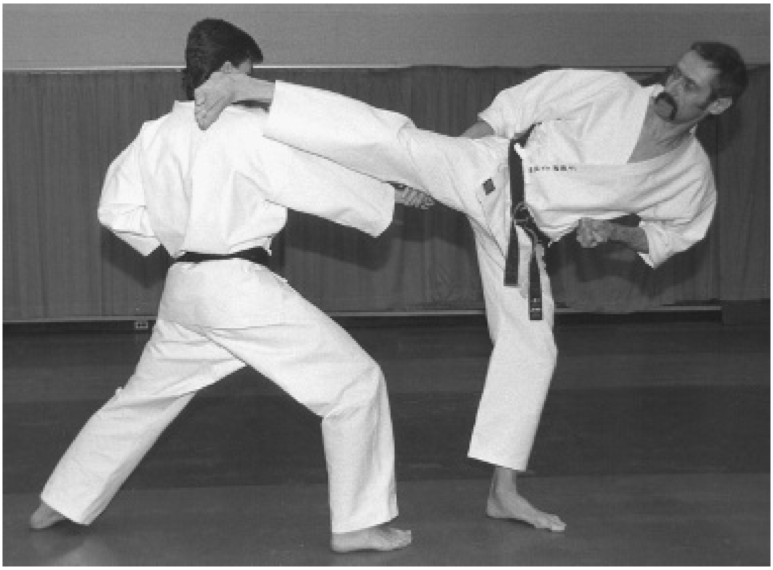
10.8.2.4.1 Observation of Physical Properties As has been described earlier, the physical properties of the present and the previous techniques are almost the same. However, in this technique, the *Shite* has very little footwork and the *Uke* has none. There is a short horizontal angular velocity from Figure 10.38d to Figure 10.38f. To calculate this short (ω), we must acknowledge that during a rotation (turning of the right foot of the *Shite*) there is also a strong pushing force involved by pushing down the *Uke*'s arm and, ultimately, his body.

To simply calculate the energy spent during the push down of the *Uke*'s arm (body), energy (E) = F (*distance*) or (E) = $m \cdot g$ (*distance*). For a 70 kg Aikidoka (*Shite*) who first pulls and then pushes down the defender's (*Uke*) arm and then his body, the distance will be counted from the upper thigh level (1/3) of the *Shite* to the ground, which is 0.76 m; the equation will be (E) = (686 N)(0.76 m) = 521.36 J. The most important motor quality is the strength and the fine motor skill of the hand of the attacker (*Shite*). The pulling force of the (*Shite*) is negligible; it represents only the continuation of the hand manipulation.

CHAPTER 11

The Biomechanics of Striking, Kicking Arts

11.1 KARATE



Karate—Back roundhouse kick (*Ura-mawashi-geri*, executed by the author).

11.1.1 General Description

Before describing karate in general, the reader should know the difference between different forms of karate. The first form of karate is the *Classical/Japanese* or points system of karate. In this type of karate, the fighter's goal is to score with punching, striking, or kicking the vital targets. This form of karate is a point system and/or noncontact karate. The attacker must withhold his punching fist or kicking leg in front of the vital area of the target. The withholding distance should be 2–4 cm (1–1.5 in.). The attack must be executed with vigor, high speed, and power in order to be considered as a destructive force.

The second type of karate is the contact type, where the attacker can hit the defender, but not with full power. In this type of karate, the combatants can wear protective gear, and in this case, the attack can be delivered with full power.

The third type of karate is the full contact karate, where the opponents can hit each other with all the power that they have. Some parts of the body are excluded from being hit, such as the kidney, the front and back of the neck, and of course the groin area. We will not describe this type of karate in this book.

11.1.2 Anatomophysiological Considerations

Karate is a very dynamic sport. During the fight the sustaining effort is less than in other martial arts such as judo, sambo, or wrestling. The effort is sustained in a standing position. The fighter's balance can be maintained easily by moving constantly, changing directions related to the opponent or not related to the opponent's attack.

In karate, the attacks are almost 100% linear, so the balance can be maintained very well. In defense, the karateka who moves back in a straight line still can maintain his balance well. However, the difficulty to maintain the balance occurs when the defender shifts his body in a different direction in order to avoid the head-on attack.

During a conventional/point system of fight, which is about 2–3 min long, the fighters have a high ventilation and a high elevation in blood pressure and the fight is considered to be under the motor quality of the speed, which is conducted with a very high endurance regimen. The fight is considered to be a very high aerobic activity. Combination in attack is used mostly in the point system of karate and those are very spectacular features.

In contact or full contact type of karate, the simplest actions or techniques are used in order to K.O. (destroy) the opponent. Using

combinations, for example, high kick to the face + ridge hand strike to the face + reverse punch to the stomach area will take about to 2 s. Using a simple attack to be kick or strike takes less than 1 s.

The reader will ask: so what is the difference and why? In a conventional point system of karate, during a combination, an opponent can stop the attack, but the attacker will not be hurt physically. In full contact type, each fighter tries to execute the fastest attack not giving any chance for the defender to use a stopping attack. Also, it is known that an attack is most of the time faster and stronger than a stopping or counterattack. A stopping attack requires excellent timing. During a combination one–two, the stopping hit must precede the second attack of the combination. This is the key of success for a stopping attack.

11.1.3 Objectives

After reading this chapter, you will be able to understand and do the following:

- Which are the most important physical properties—name three that are used in karate?
- Explain when the high standing or low standing position should be used during a fight.
- Explain the advantage or disadvantage using arm, leg, or sweeping techniques. Give some examples.
- Describe different techniques conveniently used by a tall karateka and by a short karateka.
- Is there any leverage used in karate? In what action or technique?

11.1.4 Biomechanical and Technicotactical Principles in Karate

In karate, the most important physical property is the speed. The second most important physical property is the force/power. Earlier, the difference between force and power has been described. A good instructor should have a good knowledge how to teach his athlete, explaining the usage of these physical properties. Apart from using one's own speed and power, there is the opponent's speed and power that the attacker should take into consideration.

11.1.4.1 General Principles

In karate, the majority of the attacks are executed linearly. However, in any technique, which seems to be a linear attack, there is a rotary execution

as well. Karate attacks emphasize linear executions that are faster than rotary attacks. However, rotary attacks have more power in the attacks if the attack is executed in a large circular motion; then the attack has acceleration.

- Both karateka (attacker and defender) must keep their CoG permanently in the middle of the body. The attacker's height should always be at the same level with the floor, not standing higher or lower. In this case, the body changing situation will be executed much easier. The defender should stay in a deeper position to enlarge the BoS. In this way, the defense will be much stronger.
- There are three important factors that are strongly interrelated to each other and those are distance (*Ma*), timing, and speed (*Hayasa*). The most important is the distance, then comes the time, and finally the speed in your action.

The principles of point system or light contact karate differ greatly from full contact karate. *Some of the point system karate principles are as follows:*

- Keep in mind that kicks are much stronger than striking/punching techniques and for this reason use your distance accordingly to your opponent's distance.
- A kick will reach his 100% full delivery force when the kicking leg is extended approximately for a distance of 75% from the attacker. Actually the driving of the hips (using the stance leg to push the hips can account for much of the resultant force, especially in thrust kick). The remained 25% distance is used for penetration. A distance shorter than 75% prior to finalizing the kick will have less power ($P = F \cdot v$). If the distance is longer than 75% before reaching the target, then the power to be set into the kick will be less again.
- Before using the kicking technique, the attacker should use an arm technique (false attack). If the attacker starts to use a direct kick, the opponent will move further back and in this case the kick will not be efficient.
- The defender should stay as close as possible to the attacker in order not to delay his counter techniques.

- Before using any sweeping technique, the attacker should use feints with his arms.
- Using the front leg for sweeping the technique of execution will be much faster, but less efficient because there is less power.
- Using the rear leg, one can make the action more powerful because of shifting and the longer distance that the rear leg has over the front leg. For more description, see Sections 11.1.9.1 and 11.1.10.
- The attacker should use almost all the time combination techniques. In this way, one of the techniques will reach the target for a point.

Principles for contact or full contact karate:

- Use kicks against your opponent that are stronger than attacks with the arm.
- Use leg sweeping techniques even if not very efficient, but by using sweeping techniques the opponent will be off-balanced and your follow-up attack will have the maximum effect.

Note: Karate technique executions are much faster than any other martial arts technique, except fencing. For this reason, karate deals not only with the biomechanics of the technique but also with the physiological and psychological problems. These factors should be used correctly in karate classes.

11.1.5 Hand–Arm Techniques (*Te-Ude-waza*)

In karate, there are more punching and striking techniques than in boxing. There are at least 20 different kinds of punching and striking techniques in karate. In this book, we will analyze mechanically only few and those are most known and used more commonly.

11.1.6 Punching Techniques (*Tsuki-waza*)

Four punching techniques are described here: reverse punch, lunge pushing punch, reverse pushing punch, and lunge or stepping punch.

11.1.6.1 Biomechanical Analysis of the Techniques

The most important principles—body rotation and fist rotation—are described under the biomechanical analysis.

11.1.6.1.1 General Principles in Punching Techniques There are two general principles in the four punching techniques: fist rotation and body rotation.

11.1.6.1.1.1 Fist Rotation The physics/mechanics of fist rotation is similar that of the rotating bullet from a gun. Usually, the fist that is ready to punch forward is kept closed to the side of the hip. The fist is clenched with all the fingers into the palm by folding all the phalanges (except the thumb) into your palm. The thumb will press on the second phalange on your index and middle finger. The entire fist is at your side (at hip level or higher) and all the fingers are visible when you look down at them.

When the fist is pushed forward for punching, it should be rotated 180° before reaching the target. The more late you twist before reaching the target, the more penetrating power you will accumulate. This twisting of the forearm with your fist becomes a weapon like a spear.

11.1.6.1.1.2 Body Rotation The great majority of the dynamic forces utilized in karate techniques are generated by rotating the body, the shoulders, and especially the hips. It is not uncommon in other sports and fighting art forms, such as discuss throwing, javelin throwing, boxing, and kung fu, to deliver the strength from rotating the hip first and then rotating the shoulders and the forearm with the fist.

It is well known that the lighter the body segment, the faster one can be, but one generates less power. The heavier the body part, the more power one can generate, but the speed will be less. Much more can be said about hip rotation and about "body vibration," but we will not analyze these features.

Summary for Part IV has explained the *semipermanent contact/link* sports, where karate, boxing, and others were included. For this reason, some techniques will be described first with static position with no opponent involved at all and then with the dynamic position (*semipermanent contact/link*) conception.

11.1.6.2 Reverse Punch (Gyaku-zuki)

Let us say the executor stays with his left foot in a forward position. The position can be similar to a boxer's fighting position. In karate, this position a little bit deeper and the distance between the front leg (left) and the rear leg (right) is larger (Figure 11.1a and 11.1b).

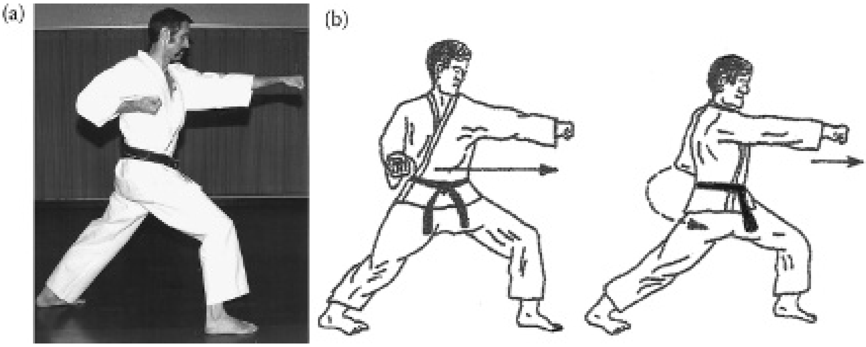


FIGURE 11.1 Reverse punch (*Gyaku-zuki*).

Take a look at the right side of Figure 11.1b. From a left fighting position (*Hidari Zenkutsu-dachi*) with the left arm extended and the right knee slightly bent, the right hip starts to rotate to the left and the right fist with the right shoulder starts to move forward.

On impact, the shoulders are parallel with the target or the right shoulder is in a slightly advanced position (Figure 11.1b) in comparison with the left shoulder. The reverse punch technique can be executed from other fighting position as well. These positions will not be described in this book.

11.1.6.2.1 Observation of Physical Properties Under reverse punch, obviously we have the momentum. We do not have the impulse and not even the force (except the muscular one) because we do not have a contact point that could change the momentum into impulse. To find the velocity, we have to use $(v) = \Delta\text{position}/\Delta\text{time}$. The question here is where or what is the final position? The final position should be when the punching arm is completely extended.

The initial position starts from the point where the fist was held close to the side of the body (under the armpit or a little bit lower). The time of execution will not be accurate measured using a hand-held time clock.

Because of the extremely short distance and the speed of the karateka, the time will be measured within milliseconds. The distance can be measured before timing. The following calculation will be done when the karateka does not step forward so that the execution is done on the spot with only the punching arm. We can measure the power of the execution, which will be $P = F \cdot v$ (N · m/s). If we choose only one punching arm mass (about 3.45 kg), living out the rest of the body's force, then we will have the equation for a 70 kg karateka, $P = (34\text{ N})(9\text{ m/s}) = 306\text{ N} \cdot \text{m/s}$ (W). The 34 N matches up

for the total arm length, including the closed fist. The 9 m/s is the generally accepted average speed for a punching arm of a black belt karateka.

The 34 N is an average number. Calculating the kinetic energy spent, will have

$$KE_{\text{linear}} = 1/2\ m \cdot v^2 = 1/2\ (3.45\ \text{kg})(9\ \text{m/s})^2 = 139.72\ \text{J}$$

The mass 3.45 kg is an approximate number for a total arm length including the fist. In the following, we will describe different circumstances where the karateka will meet an opposing target.

1. The karateka has a mass of 70 kg and tries to break a solid wood panel of 30 mm thickness, but he *could not* break it. His forward speed is 13 m/s. The rebound speed from the wood is 7 m/s. The contact time of his fist on the wood is 0.10 s. Find out the impulse of the karateka and the rebound force on the wood.

   Given: *Mass* = 70 kg; however, we use only one complete arm mass and a relative mass of his shoulder, which he uses to push forward his punching arm and this is a total of 7 kg *mass* (we neglected the *mass* of the hip). To resume, the arm and the shoulder mass = 3.45 kg + 7 kg = 10.45 kg. $v_i = 13$ m/s, $v_f = 7$ m/s. Impulse (J) = Δmomentum (p) = $m\Delta(v_f - v_i)$ = (10.45 kg)(–7 m/s – 13 m/s) = (–209 kg·m/s).

   The karateka's impulse (J) = –209 kg.m/s. The rebound impulse force of the wood is $J = F \cdot t$, then, $F = J/t$ = (–209 N · s)/(0.10 s) = –2090 N. Actually, the driving of the hips (using the back leg to push/rotate the hips) can account for much of the resultant force, especially in thrust kicks.

   If the karateka *broke* the wood, then obviously the rebound force will be very minimal or reduced to "0," considering the time of contact of the fist. If we hypothetically eliminate the time of contact of the fist to "0" second, then the actual force of the arm and the shoulder remains N = (10.45 kg)(9.8 m/s^2) = 102.41 N.

2. (A) When the karateka hits the opponent abdomen. (B) When the karateka hits the opponent's chin. When hitting two different surfaces with different structures, the reaction forces will be different.

11.1.6.3 Lunge Pushing Punch (Jun-zuki No Tsukkomi)

See Figure 11.2a and 11.2b.

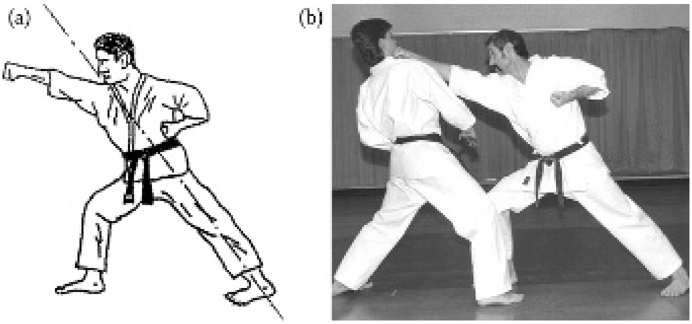


FIGURE 11.2 Lunge pushing punch (*Jun-zuki No Tsukkomi*).

11.1.6.4 Reverse Pushing Punch (Gyaku-zuki No Tsukkomi)

See Figure 11.3a and 11.3b. Lunge pushing punch is very similar to karate basic punch "Lunge Punch" (Jun-zuki) (which will be described later) and is executed with the upper body in an erect vertical position. In lunge pushing punch, the upper body will not be kept at the vertical level, but on impact, the upper body will incline forward. In the final position, the rear leg and the upper body should be in the same line, creating an approximately 45° angle with the ground.

Reverse pushing punch is also similar to reverse punch described before (Figure 11.1a and 11.1b). At the impact, the upper body will incline in the same manner as in lunge pushing punch execution.

What is mechanically significant in these two techniques? The role of the mass of the karateka is important because the technique is not executed as a so-called "Snap-punch" (a reverse punch of withdrawing quickly the punching arm from the target); however, the time is also important

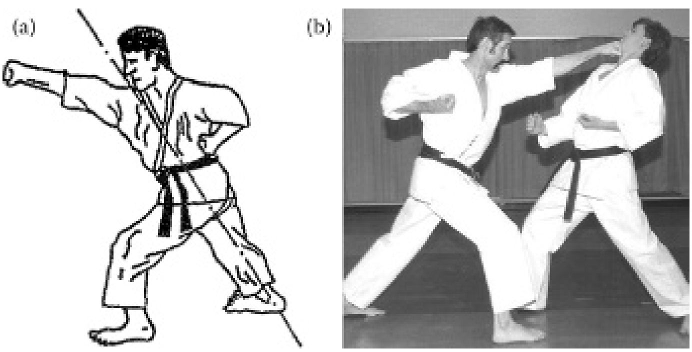


FIGURE 11.3 Reverse pushing punch (*Gyaku-zuki No Tsukkomi*).

because at the pushing action, the fist will be in contact with the opponent's face for a longer time. So how are the momentum and the impulse related to each other?

11.1.6.4.1 Observation of Physical Properties Taking into account the previous example, the "reverse pushing punch" *(Gyaku-zuki No Tsukkomi)*, the momentum and impulse will be as follows: The karateka has a 70 kg total body mass. The punching/pushing arm and the shoulder mass is ~10.45 kg; it is the same as the previous example. The initial velocity (v_i) = 15 m/s. The final velocity (v_f) = 11 m/s. Both velocities are higher because of the longer distance and prolonged pushing time (action) of the punching arm. The contact time on the opponent's chin is 0.20 s.

The momentum (p) = $m\Delta(v_f - v_i)$ = (10.45 kg)(−11−15 m/s). In this technique, the Karateka's impulse (J) = −271.7 kg.m/s. The rebound force from the chin of the opponent is $J = F \cdot t$, then $F = J/t$ = (−271.7 N.s)/(0.20 s) = −1358.5 N. Basically, the recoil of the head must be taken into account. Before the collision, $m1$ has $v1$ + $m2$ has $v2$ (say $v2$ of the head = 0) and after the collision, $m1 \cdot v3 + m2 \cdot v4$. For simplifying the equation, we did not calculate by using the aforementioned equations.

What can be deduced about the last number −1358.5 N? The force will be reduced because of the longer contact time on the chin.

Other considerations about punching techniques:

1. Punching soft targets such as the abdomen. Here, at the time of contact, we should consider the energy released and deposited into the punching area to damage that soft area.

2. Punching hard objects such as the chin of the opponent. Here, the contact must be sharp and short in time. Mostly, the contact will not go too deep into the target. The sharp contact on the surface (chin of the opponent or hard objects such as wood, tiles, etc.) will do enough damage because of the shock wave of the force that travels through the object.

3. Using reverse punch (*Gyaku-zuki*), the focus on the technique is to liberate a maximum force in the shortest time. In this case, the rebound speed has the maximum efficiency to destroy a hard target. Interestingly, the reverse pushing punch (*Gyaku-zuki No Tsukkomi*) is similar to the reverse punch technique, which also targets only the chin of the opponent; however, the force is delivered for a longer time. The

attacker by inclining his body forward can reach the defender's chin. The punching time is not significantly longer than in the case of *Gyaku-zuki*; however, the time is longer because the target is further on.

11.1.6.5 Lunge or Stepping Punch (Jun-zuki or Oi-zuki)

See Figure 11.4a–d. This technique is not much different from the *Jun-zuki No Tsukkomi*. In this technique, there is no upper body leaning forward, so the total body speed is relatively higher because the CoG is not fluctuating. This technique is used in competition instead of the lunge pushing punch. There is not much to describe about this technique. Figure 11.4b shows a little off-balancing position. But the recovery is instant because the speed is constant.

To be successful in this technique the speed and body equilibrium is of prime importance. If the karateka chooses a fighting position that is higher, then his speed will be better than using a long fighting position such as "Front Stance" (*Zenkutsu-dachi*)—Figure 11.4d.

In order to have a better speed, the attacker before stepping forward using the "lunge punch" will pull back his left foot just a short distance (about 30 cm), then immediately move forward with his right foot with the lunge punch technique. By using this technical maneuver his equilibrium also will be better. This movement is not shown in any of the above figures.

11.1.6.5.1 Observation of Physical Properties What kind of physical properties are involved in this technique? We can calculate the momentum, kinetic energy, velocity, acceleration, and friction.

Let us calculate the kinetic energy with no contact to the opponent or any other object. KE_{linear} = 1/2 kg (m/s)^2. The karateka has a 70 kg body mass

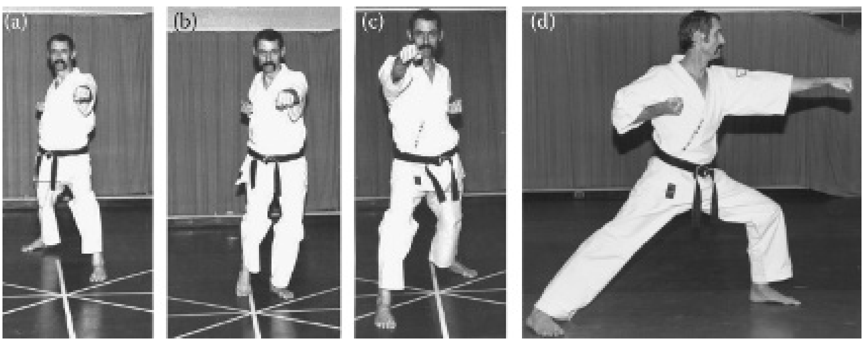


FIGURE 11.4 Lunge or stepping punch (*Jun-zuki* or *Oi-zuki*).

and with velocity $(v_f - v_i) = (0.20–0) = (1/2)(70 \text{ kg})(0.20 \text{ s})^2 = 1.4$ J. In martial arts in general and in karate techniques in special, the friction forces are present all the time, not only the static but also the kinetic friction forces.

In karate, when stepping occurs for an attack (approaching the opponent), the attacker always brushes the floor with the ball of his foot with a hard kinetic friction. The foot that remains behind is used for a strong static friction, which creates basically a very good stability and furthering strong propulsion forward. We will not give any example to calculate the friction forces. Friction forces have been described earlier in Section 8.3.

11.1.7 Striking Techniques (*Uchi-waza*)

Striking techniques use a semicircular motion aimed at the target. Striking techniques involve the snapping action of the elbow and rely a great deal on the third law of Newton, which states that for every action of a force there is a counter and opposite action of force. How exactly does the third law of Newton work? The reader should ask, where is a punch, strike, or kick from where one should be returning/bouncing back force (strike or kick force).

When a strike is executed with no contact at all, after the whipping action, there is always a returning action (bouncing back) of the forearm. The harder the whipping action of the strike, the harder will be the returning forearm that executed the strike. It can be said that the returning forearm acts like a spring that was extended and released and that returned to the original place.

The strike is executed as a whipping action and this is done from the elbow. This kind of whipping action can also be seen in kicking techniques. Striking techniques are executed as rotary movements. Punching and kicking techniques are also executed as rotary movements (this should be understood by relating the extension of two limbs), for example, upper and forearm or thigh and calf. The linear execution of a kick or a punch is related to the linear displacement of the technique. In punching execution, the arm/fist never returns back from the starting position. Do not confuse this last sentence with the snap-punch execution. In this case, the executor will pull back the fist.

In punching techniques, such phenomena never take place. In punching techniques, the first law of Newton could be applied. Punching techniques are more powerful than striking techniques; however, striking techniques work like baseball pitching techniques. A ball thrown by a pitcher can reach speed up to 110–150 km/h.

11.1.7.1 Ridge Hand Strike (Haito-uchi)

See Figures 11.5a–c, 11.6a, and 11.6b. Ridge hand strike is extremely effective in fight. The technique is executed with a semicircular motion of the entire arm. The striking surface is the opposite side of the so-called knife hand, particularly the outer edge of the forefinger, which includes the outer edge of the second metacarpal bone and also the second finger first phalange.

The execution of this technique starts with the flexed forearm, but the total arm somehow hangs downward (Figure 11.5a). The semicircular movement

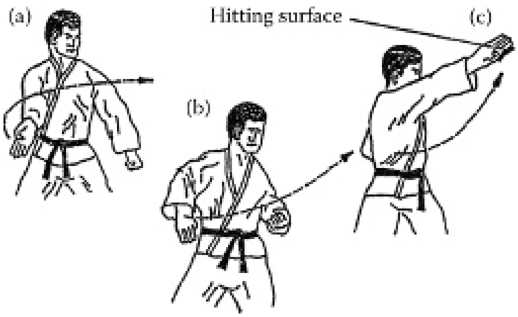


FIGURE 11.5 Ridge hand strike (*Haito-uchi*).

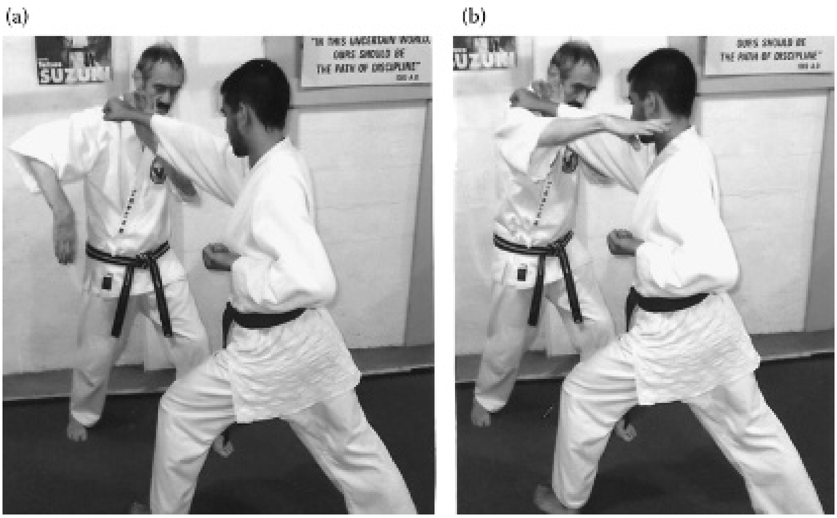


FIGURE 11.6 Ridge hand strike (*Haito-uchi*). The defender is on the left side of both figures. He blocks the attack of the opponent with an open palm sweeping block (*Te-nagashi-uke*) and then counters with the *Haito-uchi*.

starts with the elbow raised and kept far from the side of the body (Figure 11.5b). Figure 11.5c shows the final hitting position of the defender.

Keeping the elbow far from the side of the body and the hanging of the forearm is the key element of striking from snapping the elbow and giving an extra possibility for the technique to accelerate. Continue the motion by holding far the elbow from the side of the body and at the same time the elbow with the forearm will be raised to the level of execution of the strike itself. When the forearm with its hitting surface (*Haito*) approaches the attacker's target (e.g., his face), the elbow will give a snapping motion and the forearm will hit the target by accelerating.

11.1.7.1.1 Observation of Physical Properties In this technique, we can calculate the hitting power $(P) = F \cdot v$ or simply $(\mathrm{N} \cdot \mathrm{m/s})$ of the forearm, using only the mass of the forearm. The action of hitting with the forearm is extremely fast and the distance for velocity and/or acceleration is short. We will neglect any other calculations about different physical properties.

11.1.8 Hand and Arm Blocking Techniques (*Te-Ude-Uke-waza*)

11.1.8.1 Technical and General Characteristics

There is a lot to describe about blocking techniques. The author will resume describing just for the most important features that characterize blocking techniques. For successful blocking, the defender must anticipate the opponent's offensive action.

To successfully block the opponent's attack, hard and soft techniques should be used alternately. A defensive technique is also using dodging and body shifting to avoid a very hard attack. Dodging techniques are used especially against kicking.

Blocking techniques can be executed as hard or soft. When executed hard, named "Hard blocks," the arms, especially the forearms, must be tensed for maximum efficiency. For hard blocks, the forearms must be toughened, especially the ulna bone side. Correctly executed hard blocks can be considered as attacks against the attacker's limb.

Soft blocks are named "Parries" where the blocks are executed with sweeping motions by guiding the attacking arm far away from the body. Parries are executed mostly with the open palm; however, the open palm technique is not recommended to use against kicking techniques.

There are many different kinds of blocking techniques such as one-handed blocks and two-handed blocks. Another classification that has been mentioned before is the following:

1. Blocking by force. When the blocking technique is executed with a considerable force against the opponent's arms or legs, the block must be done with a fraction of second before the attack reaches the target.
2. Blocking by suppleness, which is divided into the following:
   a. *Parrying*: This kind of block is executed approximately in the same manner as the previous one but, on impact, the defender's body, especially the torso (shoulders), is rotated toward the blocking line (Figure 11.7a). The figure is also combined with a body shifting (*Tai-sabaki*), which uses the legs to position the body outside of the attacking range. By rotating the torso toward the blocking line, this block (parry) is considered an absorbed defense. The parrying must be executed with a longer contact time.

   Under the category of parrying, there are the *absorbed blocks* and they can be done; when the *Tori* attacks the stomach area, the *Uke* simply *pulls his stomach in* and *tightens the muscles* in order to avoid the remaining power that has been absorbed at the very first contact time. In this way, the full amount of the shock is dissipated. To execute an absorbed block, the defender's stomach must be in a permanent state of tension and also the timing of the *Uke* must be good for the absorbed block execution.

   If the defender pulls in his stomach muscles too late, then the total penetration power will damage the *Uke*. If the *Uke* pulls his stomach before the contact, then the continuous force of the attack could have the total effect of destruction on the *Uke*.

   b. *Sweeping* technique presupposes an earlier contact with the opponent's limb and the contact time is much longer than in parrying. The blocking motion is made as a sweeping action and the defender's blocking arm has a retreat action toward his body. The best example

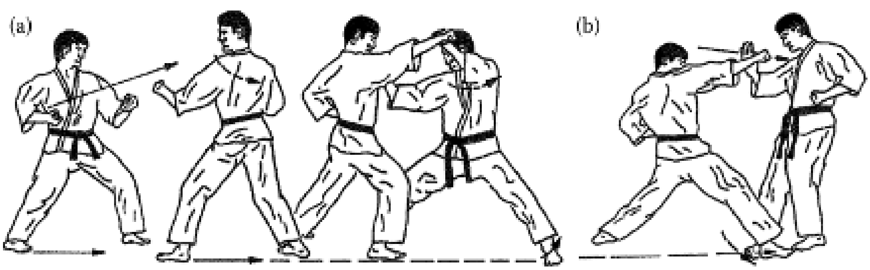


FIGURE 11.7 (a) Parrying and (b) sweeping.

is sweeping hand block (*Te-nagashi-uke*), which is executed with the palm (Figure 11.7b, see the hand action in the figure).

This sweeping technique can be combined and executed at the same time with the leg in a sweeping or hooking action as the minor inside reap/sweep (*Ko-uchi-gari* or *Ko-uchi- harai*) (Figure 11.7b, see the leg action in the figure).

c. *Hooking* techniques involve a rotation of the forearm mostly moving from inward to outward, while hooking and pressing the opponent's arm downward. We will not describe this technique further.

11.1.8.2 Biomechanical Characteristics

Blocking by force, the karateka will obviously use a considerable hitting force and also energy to be successful in this kind of blocking. The defender must be knowledgeable in the area of the attacker's forearm where the most pain can be inflicted at the time when the attacker arm will be hit. This can be almost anywhere, but it is recommended to hit the upper portion of the forearm particularly the *brachioradialis, flexor carpi ulnaris,* and *extensor digitorum* muscles.

Hitting the forearm radial part is more painful than the ulnar part of the forearm. Blocking by suppleness, which includes parrying, sweeping, and hooking, the most important attribute of these techniques is the *timing* and *distancing* of the blocking arm. Once the defender has decided the timing to block the opponent's attack, he then has three choices for blocking the attacker arm, which includes different distances between the defender and the attacker.

Here are the three choices:

1. Blocking the attack *very early*. In this type of blocking, the defender will not block the attacker's forearm as usual, but will instead block or better said stop the attacker's upper arm at the *biceps brachii* or *triceps brachii*, at the shoulder, or even at the elbow part, particularly at and around the *brachioradialis* and *flexor carpi ulnaris* muscle. This blocking/stopping technique is very effective because the attacker will lose his equilibrium; however, it is very dangerous if the timing is not set up correctly.

2. Blocking the attack in *mid-time*, when the attack is still in progress. This kind of block is used most of the time and it is relatively safe. Under this category, the sweeping technique is included. It works

this way: When the attacker's entire arm is extended ~50–60%, then the remaining 40% will be defended by moving the defender's arm toward the middle of the attacker's arm (upper portion of the forearm) and will slide backward toward the defender's body together with the attacking arm.

This way the attacking arm is controlled during the remaining 40–50% of the attack. At this time, the defender has a choice to guide the attacking arm or finally to grab the attacking arm.

3. Blocking the attack at the *last moment* before reaching the target. This is the most difficult technique to be executed because if the blocking is not timed well for the last millisecond of the attack, the attack will reach the target and the defender will be hit. This kind of last moment blocking is used only by highly trained karate experts. The advantage for this blocking is that at the time of blocking a counter technique can be delivered at the same time with the attack.

11.1.8.3 Rising Block (Jodan-age-uke)

See Figure 11.8a and 11.8b. This is a very basic block and is used against head attacks. It is very seldom used because raising up an arm takes more time than just moving the arm laterally inward or outward from the body. Also, the technique is used against the gravity. However, it is extremely effective against very tall attackers.

The forearms cross at chin height. The blocking arm (let us say the left arm) moves upward and the blocking surface of the forearm becomes the interior side called *Naiwan* (the ulna bone part). The right arm moves

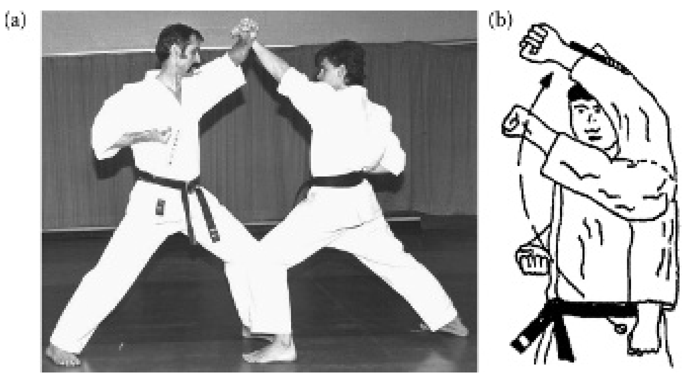


FIGURE 11.8 Rising block (*Jodan-age-uke*).

downward, stabilizing the fist tightly near the right chest under the armpit. The fist of the blocking forearm is tightened along with the abdominal and chest muscles at the time of blocking.

The blocking forearm is about 10 cm in front of the forehead, while the fist is higher than the elbow. The blocking fist's palm side looks forward. In this blocking technique, there is not too much to describe about the physical properties. This technique has a simple movement.

11.1.8.3.1 Observation of Physical Properties Obviously the speed and force can be debated. At this technique will be a physical and psychological momentum too. We can calculate the gravitational potential energy of the raised arm. $PE_{\text{gravit.}} = m \cdot g\Delta h$. The karateka has a mass of (70 kg)(9.8 m/s^2)(0.63 m) = 432.2 J. 0.63 m represents the height between the lower chest level and the top of the raised left fist.

The calculation of the power and work can also be done easily. We live this at the discretion of the reader.

In Figure 11.8b, the thick black line on the top of the left forearm of the defender represents the blocking surface.

11.1.8.4 Downward Block (Gedan-uke)
See Figure 11.9a.

11.1.8.5 Downward Sweeping Block (Gedan-barai)
See Figure 11.9b. *Gedan-uke* is used against a punch or kick to the abdomen, or lower level. During blocking, the lower portion of the forearm moves downward and laterally. The fist of the blocking arm is about 15 cm

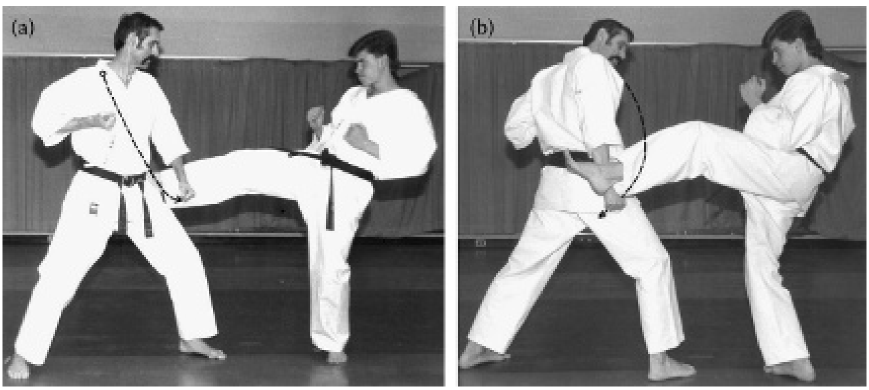


FIGURE 11.9 (a) Downward block (*Gedan-uke*). (b) Downward sweeping block (*Gedan-barai*).

away from the thigh of the front leg. (In our case, the left arm blocks and the left leg is in front).

Gedan-barai is similar to downward block, but the blocking arm does not block the attacking arm or leg but, instead, uses a sweeping motion. The correct terminology for this is *parry* rather than *blocking* technique.

11.1.8.5.1 Observation about Downward Block and Downward Sweeping Block The major technical difference is about the force that is applied for the downward block. In both figures, the defender is on the left side. Downward block (Figure 11.9a) is executed with full power of the defender. The blocking fist is elevated near the clavicle (see the small circle on the right shoulder of the defender).

The fist descends toward the left side of the defender, where the block is executed. These two blocks are usually used against kicks. The defender during blocking hits hard the attacker's *tibia* bone and the medial part of the *gastrocnemius* and a narrow medial side of the *soleus* muscles. The blocking is very painful if it is executed at the right area of the muscles described before. The execution is also aided by gravity. In this technique, at the time of hard blocking, a short impulse can be observed.

Downward sweeping block is not a hard block. It is executed by sweeping away the attacking leg. The defender starts moving his right forearm in the same manner as the previous block; however, when the fist with the forearm reaches approximately at the same level as the kicking leg (both are closed to each other), the blocking forearm will move backward alongside the attacking leg guiding it, making it useless in attack.

The momentum of the blocking arm has a certain role. The kinetic friction is very minimal because at the time of contact (forearm and leg) the blocking should be a guiding process where the two opposite body parts (kicking leg and sweeping forearm) somehow stick together.

11.1.8.5.2 Observation of Physical Properties Both blocking techniques are very simple movements. Observing the downward block, the left arm uses gravity. The blocking must use a good power where force and velocity have the same importance. If the velocity is reduced, then the kicking can be penetrated, or if the force is not enough, then the kicking leg cannot be blocked properly. Talking about momentum $(p) = m \cdot v$, both physical qualities have the same importance.

Analyzing other karate techniques of kicking, striking, or punching, there is one physical property that should prevail. This blocking technique

is executed extremely fast due to gravity and short distance. During the execution of this technique, the muscles of the shoulder and the entire arm should contract hard. This contraction should occur only at the last moment of the blocking. If the contraction does not occur, the blocking arm will be in pain during the contact time.

Observing the downward sweeping block, the sweeping motion requires longer time of execution because the contact must be kept for a longer time in order to push the attacking leg aside. This technique requires a good timing and a good upper body twisting, besides the physical qualities that have been described before.

11.1.9 Leg Techniques (*Ashi-waza*), Kicking Techniques (*Keri-waza*)

11.1.9.1 General and Technical Characteristics

Kicking techniques use the whole body to the maximum. The role of hips and body balance are especially of prime importance in effecting maximum power output. Kicking is 2–3 times more powerful than punching, but it is short of good balance. In kicking techniques, balance is very important due to the fact that the entire weight of the body has to be supported by one leg while kicking.

The supporting foot must be kept in full contact with the ground and the ankle of the supporting leg must be tensed. The shock of the kick should be absorbed by the supporting leg, mainly the ankle, the knee, and the hip. There are four major types of kicks: front kick, side kick, back kick, and roundhouse kick. During kicking, the hip has a different role, such as hip progression for front kick, hip rotation and progression for roundhouse kick, hip abduction/adduction for side kick, and hip flexion/extension for back kick.

These three types of kicks can be executed as follows:

1. Snap kicks depend for their success on snapping the leg straight from the knee and then back again as quickly as possible. Once raised, the knee is used as a fulcrum for a semicircular movement.

2. Thrust kicks rely on raising the knee first and then thrusting the leg straight using the force of the quadriceps and hip muscles.

3. Striking kicks may be used for blocking or attacking and their virtue is the flexibility of the whole leg. Kicking with the knee is considered as a striking kick; kicking with the sole or with the instep in a circular fashion is also considered as a striking kick.

11.1.9.2 Front Thrust Kick (Mae-geri-kekomi)

See Figure 11.10. In this kick, the ball of the foot or heel is used. The knee is raised high, approximately to the abdomen level, and then the leg is straightened forcefully from that position. Effectiveness comes from keeping the lower part of the lumbar vertebrae facing forward and using the power of the hip progression of the kicking leg side. The kick is used as an attack against the body's midsection and lower area.

11.1.9.2.1 Observation of Physical Properties The higher the knee is lifted up, the more forceful will be the kick. When the knee is dropped vertically (see the arrow) at the same time, the lower leg should move straight forward. For the best efficiency, the total force will be delivered when the foot at the contact time is still flexed approximately at 160–165°. The remaining 20° will be obtained from a total of 180° by the penetration of the foot into the opponent's abdomen. At this time, the attacker's leg and foot with the thigh should be completely straightened to 180°.

The front thrust kick is not entirely performed as a *rectilinear* kick, most importantly executed as an *angular kick*. Figure 11.10 shows the last part of the kick before touching the opponent's abdomen, which will turn linear.

To calculate any physical properties for angular execution such as torque, moment of inertia, velocity, power, acceleration, kinetic energy, and so on, anybody must decide from which part of the kicking leg starts as an angular motion and from which position or place starts the linear

FIGURE 11.10 Front thrust kick (*Mae-geri-kekomi*).

execution. The author describes the logical points of the kicking legs position for the angular and linear execution.

Figure 11.11 represents a front kick as a stopping attack against the opponent. This kick can be performed as a thrust or snap kick.

We have three interconnected axes of rotation. Axis (A) is at the knee, axis (B) is at the ankle, and axis (C) is at the coxofemoral area noted with three circles (see the attacker "A" on the left side of the figure). These axes are movable (swinging); they are not stationary. In our case, we also have an open muscular kinetic chain with three levers: (1) femur bone, (2) tibia with fibula bones, and (3) for the foot we have from calcaneus bone to the end of metatarsal bones, excluding the phalanges.

The small letter (*r*—radius) on the right top side of the figure represents the calf (tibia and fibula bones). The total rotation of the calf describes ~100°, from its initial position (axis A and the line through the lower leg) to the final position before the foot is extended completely when the attacker kicks the opponent (see the attack direction line). At the contact time with the foot penetration, the thigh and the calf describe a complete 180° (with penetration).

To calculate the torque is a compound challenge because the limb (calf), which rotates at the knee joint describing an angle of 100°, is

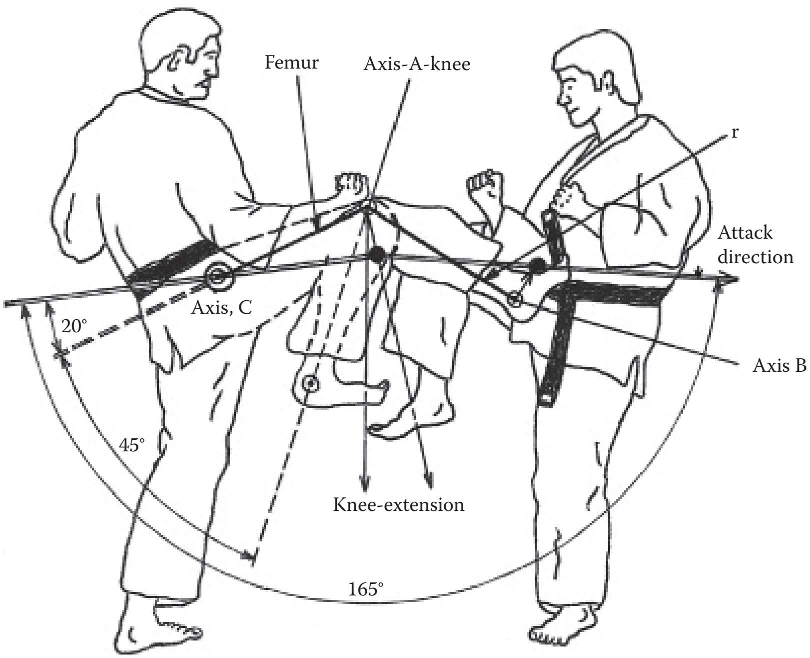


FIGURE 11.11 Front thrust kick (*Mae-geri-kekomi*).

interconnected to the thigh, which performs a small rotation also at the knee joint. The coxofemoral axis also performs a small portion of rotation and even the ankle describes a small angular rotation.

As we know, to calculate the torque, we need an axis, force, and a distance from the acting point of the force to the axis of rotation. In order to simplify but to be as correct as possible in our calculation of the torque, we will describe the components of the physical properties related to body parts that execute the kick.

The karateka possesses a 70 kg total mass, his total lower leg represents the radius (r) (the moment resistance [RA] arm); in our case, this moment arm is considered as a third class lever that is used mostly for speed actions. For the axis, we will choose the knee joint, not the patella. The reader should be aware that in our case (even) when the kicking leg advances in the forward direction, the driving forces is the *quadriceps femoris*, which is connected with the patellar ligament to the tibia acting as an extensor of the calf in a backward direction.

Interestingly, both movements (the calf as a segment moves forward but the quadriceps femoris muscle moves backward/stretches) are a positive (CCW) direction movement basically drive the calf forward into kicking movement. The torque as we know is $T = r \cdot m \cdot g$, where the r represents the total calf length 0.45 m. For the net force, we choose only the thigh muscles of the kicking leg (right), which is approximately 8 kg. Then, $T = (0.45\text{ m})(8\text{ kg})(9.8\text{ m/s}^2) = 35.3\text{ N} \cdot \text{m}$.

For simplicity, in our calculation, we *excluded* the following body parts and their movements: (1) The coxofemoral axis (C) as a rotational part was excluded. The axis (C) has a very minimal rotational movement. The thigh muscle acts as a pulling force with the patellar ligament attached to the tibia. Without this two body parts, axis (C) and the thigh could not exert a pulling force for the calf. To be correct, for calculating the entire leg torque, we should calculate the torque for each individual axis, and then add them together for a final torque result of the kicking leg. (2) We did not use the forward thrust of the pelvis musculature. (3) We also neglected the support leg (left) static friction force. Nr. (2) and (3) are important for all advanced karateka athletes.

The calculation of the momentum and impulse at the time of contact with the defender can be done. In Section 11.1.6, particularly Section 11.1.6.1.2 (Reverse Punch) and Section 11.1.6.1.4 (Reverse Pushing Punch), the momentum and impulse have been calculated against a rigid object or mass such as the opponent's chin and a wooden board.

In our technique, front trusts kick, the momentum and impulse will be calculated against a soft target such as the opponent's abdomen. Here is an example: a man of 70 kg with a 16 kg total mass of one entire kicking leg, also including a portion of the right side of the hip muscles. The hip can generate an initial velocity of 9 m/s. The 16 kg is an estimate number. The rebound speed is 5 m/s. The contact time of the foot on the abdomen is 0.20 s.

The reader should recognize that the kicking leg has less speed then the punching arm. The kicking leg's initial velocity is less; the rebound speed is also less. This is because the contact time is longer on the abdomen because of the softness of the abdomen and there is more pushing of the foot for a better force penetration.

The equation of impulse $(J)\Delta(p) = F\Delta t = m\Delta v(v_f - v_i)$, and then $(p) =$ (16 kg)(−5−(−9 m/s)). The karateka's impulse $(J) = (-224\ \text{kg} \cdot \text{m/s})$. The rebound force (if any) of the stomach is $J = Ft$. Then, $F = J/t = (-224\ \text{N} \cdot \text{s})/(0.20\ \text{s}) = -1120\ \text{N} \cdot \text{s}$. The equation results in a less penetration force than with the technique of reverse punch because of the longer contact time.

Note: The reader could ask: if the punching force is better than the kicking force, then why has it been stated in Section 11.1.9.1, that kicking techniques are 2–3 times more powerful than punching techniques? Here is another hint about the previous statement: Recall that kicking executed angularly has a better acceleration than in a linear execution; also, the mass is more obviously decisive than the punching arm mass, and because of these two factors the kicking is more powerful. However, we should not exclude the long penetration time and the loss of balance in kicking execution, which can reduce the rebound force. Generally, if the mass is large, then the impulse will be larger, and if the initial velocity is larger, then the impulse will also be larger. However, the most significant decisive factor is the contact time, which if it is shorter on the object or body, the rebound force will be significantly much larger.

Calculating the moment of inertia, angular velocity, and angular acceleration gives us some important observation about the efficiency of this kick.

The moment of inertia $(I) = \text{kg} \cdot \text{m}^2$ will remain relatively unchanged during the kicking movement. This is because the mass of the kicking thigh, leg, and foot remains at the same position (spot) related to the axis of rotation (knee) during the angular execution of the kick. All this will be changed toward the end of the rotation (end of execution). Recall that if the direction changes with constant speed then the velocity will change,

which will change the acceleration. The angular velocity (ω) will change from a slower speed to a high speed by acceleration (α).

What has happened at the last so-called 20° advancement that turns to be a linear execution of the entire kicking leg? The movement of the foot from the position of dorsal flexion will turn to be in plantar flexion position. We will neglect this short movement, which is in fact also a rotary movement (happen in a fraction of a second). Then the foot advances forward with a totally straight movement.

The reader can ask what happens with the speed which will be directed straight forward. The accumulated velocity during the rotary motion will continue and there will practically be no lost of speed in the execution of the kick.

11.1.9.3 Back Roundhouse Kick (Ushiro-mawashi-geri)

See Figure 11.12a–c. The back roundhouse kick can be executed in two ways: (1) The attacker starts to lift up his right knee in the same manner as he wants to kick a front kick, then he turns his body (in this case to the left), then lifts his kicking foot higher to kick with the heel in a backward motion to the opponent's face on the right side. Basically, the attacker will face the defender all the time. (2) The attacker will again use his right leg for kicking. He initially faces the opponent with his left leg in front, then turns around 180°, lifting up the right leg for kicking (Figure 11.12b).

This kick uses the heel or the sole as the kicking surface. This type of kick is a very powerful one. From a left fighting position (left leg in front), bring the kicking (right) leg up to the chest and turn a 180° angle, rotating the hips and the entire body to enable the heel to make contact with the back of the neck or the face of the opponent. Upon contact with the opponent's body, the upper body is leaned backward.

11.1.9.3.1 Observation of Physical Properties This kicking technique is perhaps the most powerful among all kicking techniques. Because of the body rotation and keeping the kicking leg thigh and lower leg close during the rotation, the moment of inertia is small, and the velocity is high. There is also presumably a permanent angular acceleration. Stopping this kind of kicking leg is extremely difficult. This technique is prohibited in many traditional karate competitions.

Figure 11.12 explains the way how the right kicking leg moves toward the target. Initially, the attacker stays with the left foot forward and his shoulders are oriented diagonally (see position A). The attacker will turn

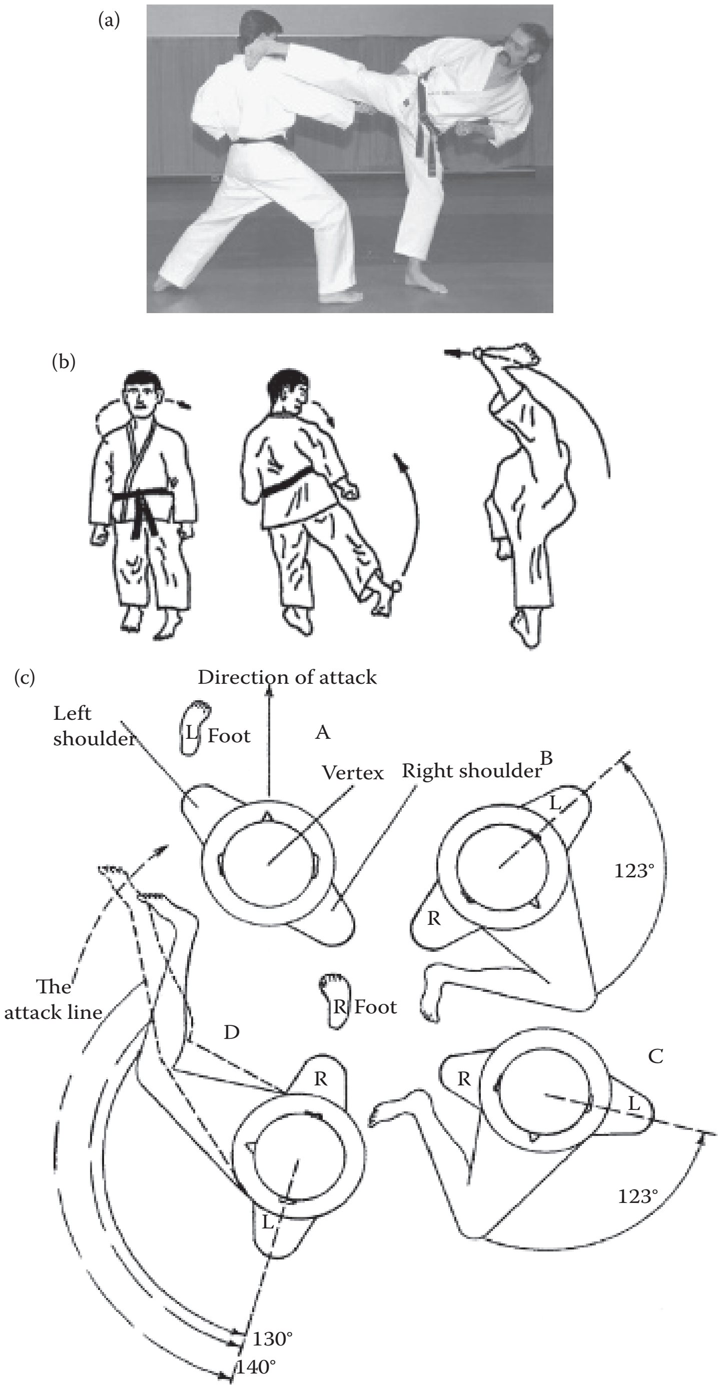


FIGURE 11.12 Back roundhouse kick (*Ushiro-mawashi-geri*).

around to his right and makes an almost 360° turn at the time of impact (face to the opponent).

During turning (see B and C positions), the attacker's right leg stays in a tucked position with the thigh and he is already turned ~180° (see A and C positions). From position C, the attacker's right leg starts to extend and at this time the moment of inertia will be very large. At the time of impact, his shoulders obviously will change positions (see D). This is a complex kick with many of the angular physical properties (here the kicking leg describes a 360° angle, and not the body of the attacker). Let us describe some calculations for this kick. The karateka has 70 kg mass; angular velocity (ω) = rad/s (6.28 rad/1.1 s) = 5.70 rad/s.

For the calculation of the moment of inertia, we are not using the entire body mass (also excluding the arms that are kept pretty far from the body during the turning process) and we will use the kicking thigh, leg, and foot only. The total mass of the kicking leg is approximately 11 kg, the radius, which includes the total leg distance, is (r) = ~0.96 m. Then (I) = $m \cdot r^2$ = 11 kg (0.96 m)^2 = 10.13 kg · m^2.

For the torque, we use the equation $T = (I)(\alpha)$, where (I) = 10.13 kg · m^2, (α) = rad/s^2 = (6.28 rad)/(1.1 s)^2 = 5.19 rad/s^2, and thus the torque (T) = 52.57 N · m.

Kinetic energy during a complete 360° turn $KE_{ang} = 1/2\ (m \cdot r^2)\omega^2$. Then, KE_{ang} = 1/2(70 kg)(0.96 m)^2[(5.70 rad/s)^2, this is the angular velocity] = 1047 J.

For calculating the KE_{ang} we used the total body mass (70 kg), including the kicking leg mass.

For work we will again use the kicking leg only, then (W) = force × displacement or $W = T \cdot \theta$ = Then W = (52.57 torque)(6.28 rad) = 330.13 J. Power $P = T \cdot \omega$ = (52.57)(5.70 rad/s) = 299.65 W.

The kicking leg $F_{radial} = m \cdot r \cdot \omega^2$ = 11 kg(0.96 m)(5.70 ω, the angular velocity)^2 = 343.10 N. Used only the total kicking leg mass (11 kg) for calculation.

11.1.10 Leg Sweeping Techniques (*Ashi-harai-waza*)

In many karate styles, throwing techniques are part of the curriculum. The throwing (*Nage*) or take-down (*Hiki-otoshi*) or *Taoshi* has been described earlier in Sections 10.1 and 10.2. In most of the traditional karate styles, the throwing is not included as part of the technical repertoire, especially because throwing somebody in competition is forbidden. However, sweeping leg techniques are permitted and used in traditional karate competitions.

Sweeping techniques can be done in varied manners. Sweeping techniques are executed against the lower part of the opponent's leg(s), lower half of the calf, and the executor can use the instep or sole as the sweeping surface. The sweeping direction against an opponent can be forward, sideways, diagonal forward, and diagonal backward.

Sweeping techniques classification:

- Using the front leg or the rear leg for sweeping in attack
- Attacking the front or rear leg for sweeping
- Sweeping used in attack or in defense (tempo sweeping)
- Feint sweeping, used for combination

11.1.10.1 Attacking the Front Leg (from Inside) (Ko-uchi-harai) Using the Front or Rear Leg for Sweeping

See Figure 11.13a–e. This is the most used sweeping technique because the opponent's front leg is close to you and, for that reason, you can more easily sweep that leg. To sweep the front leg is not an easy task because it can be easily withdrawn.

However, for an opponent who tends to lean forward and put his weight on his front leg, the sweeping technique will be more effective. The sweeping direction can be any of those that have been described above.

The defender (*Uke*) is on the left side of the figures. The attacker (*Tori*) grabs (Figure 11.13a) the defender's left sleeve from outside with his left hand (a little dot indicates the grabbing). At the same time, with the grabbing of the sleeve, the attacker will slide his left foot forward close to the *Uke*'s left foot. The arrows in Figure 11.13b indicate a force couple action.

The left hand of the attacker pulls the sleeve toward the left and down. At the same time, the left leg sweeps the inside of the *Uke*'s left leg toward the right. This is a force couple action. Figure 11.13c–e demonstrates the sweeping and falling of the defender.

11.1.10.1.1 Observation of Physical Properties In order to be successful in this leg sweeping technique, the defender should have his BoS pretty large and the weight should be supported equally by his legs or more weight should be held on the front leg. Pulling the defender's left arm we can consider that this arm acts as a lever. However, if you pull only the arm and do not sweep the leg, then the defender will not fall down.

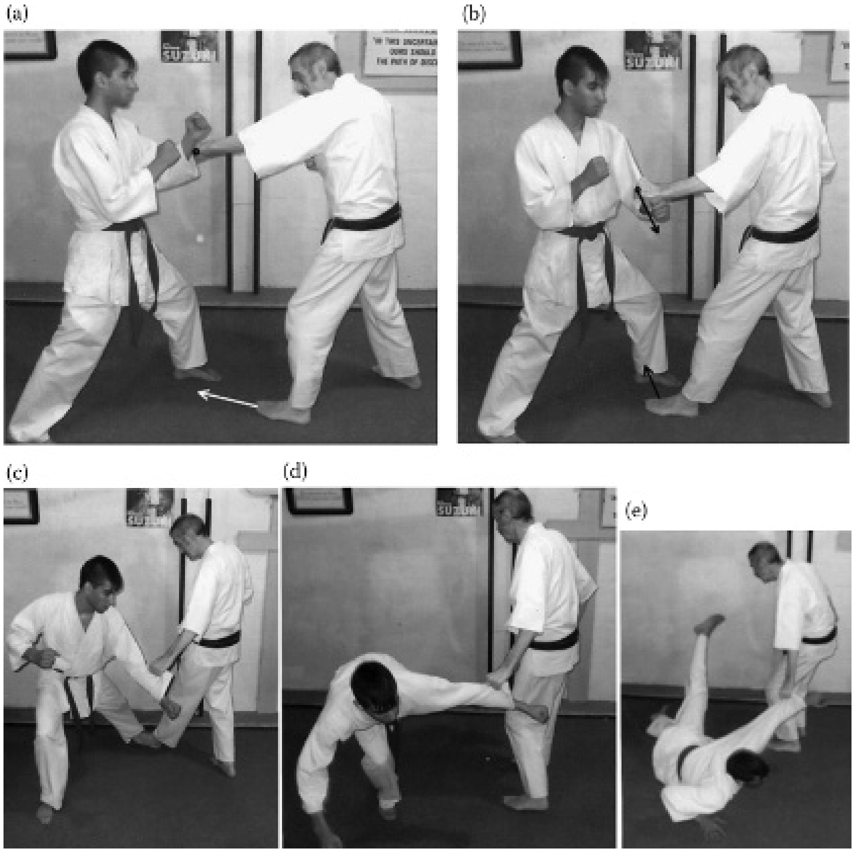


FIGURE 11.13 Front leg sweeping.

So, how can it be considered that the left arm of the defender is a lever moment arm? Where is the axis of rotation? Can the axis of rotation be the shoulder joint or the coxofemoral joint? And also which is the force moment arm and which is the resistance moment arm?

Analyzing the described paragraph before, we cannot find an exact answer; however, we should assume that the axis of rotation can be at the stomach level of the defender. We know that force couple produces torque and the forces will be rotary. The rotary movement could be considered if the defender rolled forward. The defender cannot be rolled forward because one of the forces cannot continue the rotation and the force couple will be stopped and the defender will be dropped on the mat in a prone position. The paragraphs described before are mostly theoretical explanations. But we will reassume the descriptions about some physical

properties. We can calculate the momentum and also the impulse. The impulse will be minimal because the defender will not fall down strongly on his abdomen; instead, he will use his right arm to minimize the force of contact with the ground.

To calculate the potential energy is relatively simple; it is done from the ground up to the standing position of the defender. In this case, $PE = m.g.h$. We are most interested in kinetic energy from the standing level to the floor level. Let us say the defender has a 70 kg mass. The final (just an estimate) velocity from the standing position to the ground is $v = 1.10$ m/s. Then, $KE = 1/2\ m \cdot v^2 = 1/2(70 \text{ kg})(1.10 \text{ m/s})^2 = 42.35$ J.

To find out the acceleration of the falling defender, we will use only the gravity = 9.8 m/s^2. Calculate the power (P) = N · m/s. If a 70 kg defender has 686 N and is 1.8 m tall, then $P = (686 \text{ N})(1.80 \text{ m}/1.10 \text{ s}) = (686)(1.63) = 1118.2$ W. For the distance in meters we choose the height of the defender.

11.1.10.2 Attacking the Front Leg from Outside (De-ashi-harai)

The attacker (*Tori*) is in the right side of the figures. After blocking the defender's initial punching attack (Figure 11.14a), the attacker guides the defender's left arm toward his body (Figure 11.14b) and then will grab the sleeve of the kimono (Figure 11.14c). Holding the grabbing position on the defender, the attacker set his right foot behind the defender's left foot and is ready to sweep the defender (Figure 11.14d). At this time, the attacker can proceed for the sweeping in many different ways:

1. Sweep the defender's left foot diagonally forward and to the right of the defender. Pulling the sleeve should be directed downward completely or a little bit to the left and downward of the defender.

2. Sweeping the defender's left foot straight forward. In this case, the attacker should grab the sleeve at the elbow level or a little bit higher because the attacker will be situated completely at the left side of the defender and in this case holding the sleeve lower than the elbow level, the attacker has little chance of using his strength correctly against the defender's arm.

3. This sweep is a pushing motion diagonally forward by the attacker toward the defender's right side. This sweep could be also considered as a kick. In this case, with the help of the pulling down on the sleeve, the defender's body will somehow be twisted on his

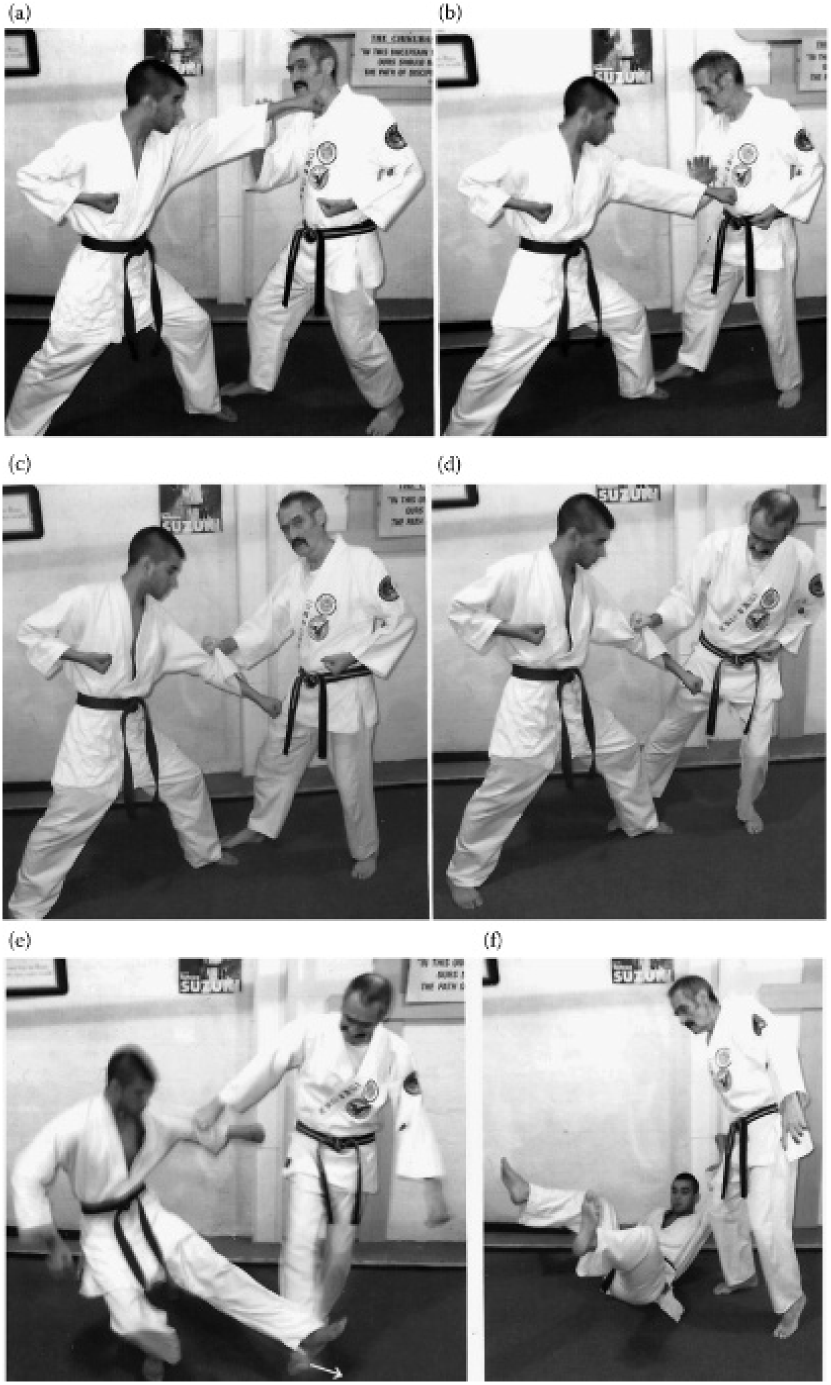


FIGURE 11.14 Front leg sweeping.

longitudinal axis. Figure 11.14e shows the nr.2, option. Figure 11.14f shows the defender's position when he loses his balance and will fall down. The holding position of the sleeve should be at the elbow pit level.

11.1.10.2.1 Observation of Physical Properties This technique can be executed somewhat easier than the previous one for the following reason. The attacker's pulling arm and sweeping leg somehow working in better synchrony than in the previous technique. In the previous technique, each limb (pulling arm and sweeping leg) had mostly opposite actions; however, in this technique the attacker first must block an attack, then grab the sleeve of the attacking arm, and finally sweep the defender's leg.

In the previous technique, there was no attack to be blocked. The attacker simply grabbed the opponent's sleeve and proceeded to the sweeping technique. When you have to block an attack, you try to grab the arm that attacked you; then you have more difficulty to execute any sweeping technique. First of all grabbing a karateka's punching arm is a very difficult task, almost impossible. If the grabbing has been done successfully, then the sweeping will not be easily executed, because a grabbed arm will create a reaction from the opponent. This reaction can vary in different ways: pulling, pushing, twisting, and so on. Using one of these actions from the defender, the sweeping attack can be delayed or simply cannot be done correctly.

Let us see what kind of physical properties are we dealing with? The momentum for both karateka can be seen. The attacker who blocks the defender's attack must deal with his motor reflex (unconditioned) to block the attack.

This sweeping technique can be done in two ways using different motor qualities: (A) In the sweeping execution, the attacker must emphasize on his sweeping speed and force that is equal to power. (B) The sweeping execution must be guided using the motor quality of skill where the leading arm that pulls the opponent's sleeve should skillfully guide the opponent for the sweeping technique to be successful. Using alternative (B), the execution will take more time.

11.1.10.3 Examples of Different Leverage for Attacking the Front Leg (from Outside) (De-ashi-harai) Using the Attacker's (Tori) Front Leg

In a classical karate competition, it is extremely rare to grab an opponent's sleeve; that is why the sweeping happened mostly without grabbing the

defender's kimono sleeve. However, if there is an opportunity created by the attacker, then the grabbing of the sleeve of the opponent will create a lever for the attacker and the sweeping technique will be executed more easily than without contact on the sleeve.

With no contact on the sleeve, the attacker basically does not sweep the opponent's leg but rather kicks his leg with a sweeping kind of motion. For hard kicking, the attacker will get a warning/penalty. Before kicking the opponent's leg, the attacker must create an ideal condition. The attacker should induce different movements (feints and/or false attacks) that will unbalance the opponent. When the opponent loses his balance or is on the way to lose his balance, then is the time for the attacker to execute the sweep or better said the sweeping kick.

Let us examine when the attacker has grabbed the sleeve and is ready to sweep the opponent's front leg. Grabbing the kimono, including the front part of the collar, shoulder, sleeve on the upper arm part, elbow pit part, and lower arm part, will create different leverages and different opportunities to sweep the opponent's front leg.

1. Grabbing the front part of the collar is disadvantageous compared to grabbing the sleeve. If you grab the collar or the shoulder, and pull your opponent to lose his balance, you have to deal with a large mass, particularly the shoulder mass or even the total body mass. Grabbing the front collar is used for two legs sweeping technique. We will not describe the two legs sweeping technique at this time.

2. Basically, there are two parts in grabbing the sleeve, which are used for helping the sweeping to be successful. Grabbing the elbow pit is the most advantageous for two reasons:

   a. Grabbing the elbow pit is most successful for the attacker because the sleeve elbow pit part is pretty much wrinkled where the sleeve is not smooth and stuck to the forearm. By grabbing this part, the attacker can maneuver the defender's arm using, for example, as a resistance (lever) arm (Figure E).

   b. If the grabbing happens on the very low part of the sleeve (close to the defender's wrist) and then you try to off-balance the opponent by pulling his arm, you may not succeed because your opponent's resistance lever (RA) arm will not act in unison with the

upper part of his body. In other words, you will move only his arm.

The sketches below show different foot positions for sweeping and two different leverage possibilities, which are followed by explanations.

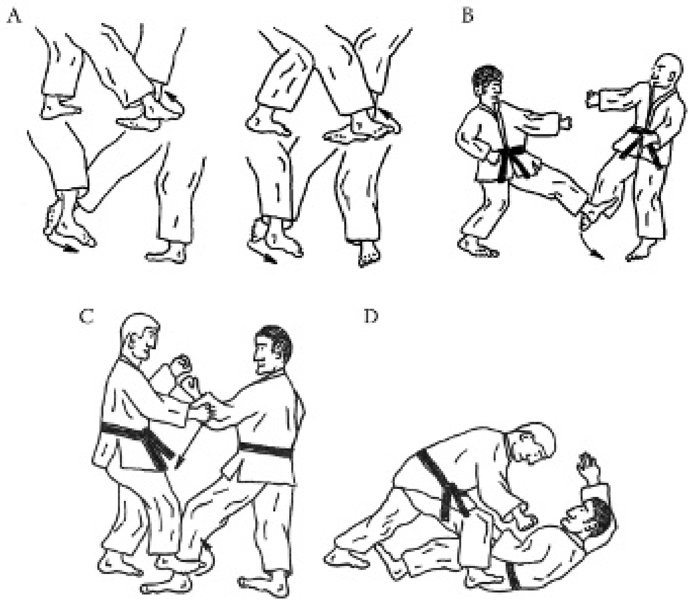


Figure A represents different foot attacks for sweeping positions. The top left is executed with the inside edge of the foot. The top right is executed with the sole of the foot. The bottom left is executed with the inside edge of the foot and the bottom right figure is executed with the instep of the foot.

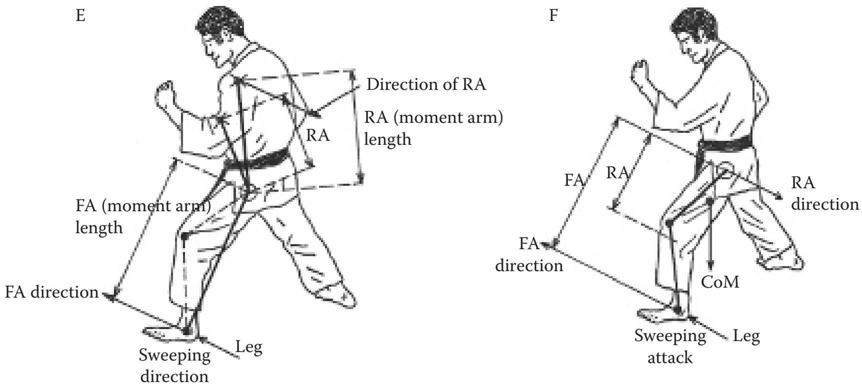
Figure B represents the actual sweeping of the *Uke*'s leg by making him lose his balance. Here, there is no sleeve grabbing.

Figure C represents initial grabbing of the *Kimono* sleeve and the continuation of the sweeping attack. The arrow shows the pulling direction of the attacker.

Figure D represents the position on the ground of both karateka.

In all the figures, the attacker (*Tori*) uses his right foot to sweep the *Uke*'s left foot. The arrows represent the sweeping direction of the attacker.

Figures E and F show two levers with very similar sweeping positions but a different arm action of the attacker. The different leverages are for sweeping with relation to the arm that grabs the *Kimono*.



Note: In Figure E, there are two Xs. One is at the shoulder and the other one is at the elbow level. For this reason, there can be two RA that depend on the attacker where he grabs the *Kimono*. In Figure F, there is no grabbing of the opponent's *Kimono*.

Figure E represents a first class lever where the axis is in the middle of the two forces (FA or effort arm and RA or resistance arm). At the first class lever, the FA can be longer than RA or vice versa; in our case, the FA is longer. Figure F represents a second class lever where the axis is at the end of the lever arm. In both cases, the axis is at the coxofemoral articulation of the karateka and is represented by a large circle (O). The FA is always longer at the second class lever.

For a better understanding of how these two different levers work, it is important to provide some details about them. Interestingly, the majority of the first class lever FA and RA act in the same direction, for example, seesaw (both FA and RA acting downwards, toward the ground). In our case, both forces act in opposite directions just like a scale working in an unbalanced position. The effort (moment) arm is stronger than the RA, so the FA determines a rotation of the RA in the opposite direction. The shank and the thigh should work together as the FA (moment arm).

In Figure E, there are two "X" signs (top of the shoulder and the elbow level). It has been described earlier that the sweeping technique will be more successful if grabbing is done at the elbow level. If you grab at the end of the sleeve and try to pull to off-balance your opponent, you may not succeed because your opponent's leg will not work in unison with your sleeve pulling action. Actually you will move the opponent's arm and not his leg.

The Figure F position is almost identical to Figure E. There are two significant positions in this figure. One is that the left arm of the defender is kept in a higher position; for this reason, the attacker will have more problems to grab the *Kimono* sleeve (which is not recommended in this case). So, for this reason, the attacker tries to sweep the opponent without contact on the opponent's *Kimono*. In this case, the sweeping must be executed extremely energetically and forcefully.

Let us describe the forces seen in Figure F. Here, the FA is the same as in Figure E. The RA forces, particularly the *biceps femoris, semitendinosus,* and *semimembranosus*, act together by opposing to be in extended position (refers about the shank and the thigh). In addition, the CoM of the thigh and the gravity act together as the RA.

The reader would ask how can there be two different levers for the same kind of action. For this reason, the author described the lever positions at the time of sweeping and also the additional features (such as grabbing) that could help to understand the similarities and differences in these two levers. The reader by now should know that levers in mechanics are not just simple bars. In human biomechanics, the levers are bones, but they are connected to muscles that can help or oppose for different levers.

Basically, levers are always established between two segments of the body. In our case, the first class lever involves three body segments, such as the shank, thigh, and the upper part of the body. But there are only two body lever parts: The whole leg and the upper body (see the thicker lines between the foot and the coxofemoral joint and between the coxofemoral joint to the shoulder or the elbow).

In Figure F, there are only two body link connections. The reader should know that opinions between biomechanists about establishing levers sometimes are confusing. In martial arts, it is even more difficult to establish a correct leverage.

11.1.10.4 Sweeping in Defense (Tempo Sweeping)

See Figure 11.15a–c. In the previous two leg sweeping techniques, the attacker (*Tori*) was the person who executed the sweeping technique. In this technique, the defender (*Uke*) is the person who executes the sweeping technique. This kind of leg sweeping requires a high technical accuracy and extremely good timing from the defender. Basically the defender must be fairly close to the attacker. In Figure 11.15a, the defender executes a sweeping block against a punch directed to the face. The defender has the choice of not blocking the attack but avoiding (weaving the head).

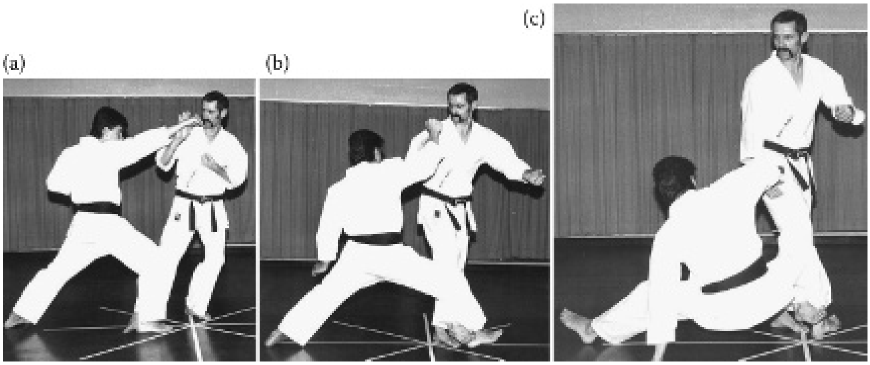


FIGURE 11.15

When the attacker steps forward into a front stance to execute a stepping punch (*Jun-zuki*) and before the attacker's foot reaches the ground, the defender must sweep the leg.

The sweeping basically is extremely easy if the attacker did not set down his front leg. If the front leg is already down, then the static coefficient of friction ($\mu_S = 0.28$) will be high considering a wooden floor and the sweeping cannot be done. During sweeping, the kinetic coefficient of friction ($\mu_K = 0.17$) will be low. See Section 8.3.

11.1.10.4.1 Observation of Physical Properties This technique requires a good balance from the defender besides good timing. The defender must position himself for a good contact with his right foot, which immediately must be behind the attacker's right heel to be swept. Let us examine the defender's physical properties.

The momentum is extremely important in this technique. The kinetic friction will be reduced if the attacker falls down during the sweeping technique. The work will be calculated by $W = F \cdot s$, where the s represents the displacement of the sliding foot. Power (P) = $F \cdot v$ or (N · m/s) of the sweeping execution.

For the sweeping power of the attacker's leg, we will use the entire leg force (N) plus adding (an approximate value of N) from the sweeping leg side of the hip, which is approximately a total of 156 N. The velocity from the contact time of the sweeping leg to the end of falling can be 1.1–1.3 s and the distance of the leg swept from the position (see Figure 11.15a) to the end of (Figure 11.15c) and a little bit further, when the swept leg has no further movement, is 0.6–0.7 m. Then, $P = W \cdot d/time$ (156 N)(0.7 m)/(1.3 s) = 83 W. The reader can ask why we do not use in our calculation

the force of sweeping the entire body mass. In a sweeping technique where there is no sleeve grabbing, but only a pure sweeping kick, the entire body mass can be used. In this technique, the body mass is not used; however, in any sweeping action involving an arm, obviously the total body mass is involved too.

This technique is executed with a guiding strength of the sweeping leg and combined with the timing to eliminate any friction force. This technique is easy to execute, but only when the acting time is perfect for sweeping.

11.1.11 Conclusion about Karate Techniques

Recall that the author mentioned under Summary of Part IV that the complexity of the karate does not allow to describe all the techniques and their mechanical characteristics. The author hopes that the described techniques provide everybody a pretty good understanding about the biomechanical features of the karate techniques. Extra knowledge of biomechanics, anatomy, physics, and so on is always important to study to have a better image about the described techniques.

11.2 BOXING

Boxing, a typical jab (front arm punch).

Boxing is one of the oldest martial arts in the world. The great civilization of the Sumerians, with flourishing arts and philosophy ~3600–3700 years ago, practiced a form of hand-to-hand fighting similar to our modern boxing and wrestling sports.

Much later on, before the first Olympic Games (776 BC), there was an event called Pankration. This was a form of unarmed combat and later it developed into two modern sports of wrestling and boxing. The origin of modern boxing is related to the United Kingdom, where certain fighting rules were developed in order to protect the boxers from serious injuries.

11.2.1 Anatomophysiological Considerations

Boxing can be practiced in two forms. One is professional boxing and the other is amateur boxing. Between those two is a great difference from the viewpoint of the boxer's effort. In modern movement science, there are five well-known motor (physical) qualities, which include the following: speed, skill, endurance, power, and flexibility. These five motor qualities are further subdivided.

1. Speed—of execution, of displacement, of reaction by time
2. Skill
3. Endurance: (a) muscular and (b) aerobic/anaerobic
4. Power/force/strength
5. Flexibility—refers to the joints (tendons and ligaments)

Elasticity—refers to the muscles, which is not a motor quality but important in many sports, such as gymnastics, martial arts, track and field, and others.

Taking into consideration these physical qualities, boxing is one of the top sports that includes mixed martial arts, football, basketball, and others, when it is about using these motor qualities during practice or fight.

Boxing uses all these motor qualities and less flexibility. Fighting effort is always aerobic. Oxygen consumption is very high. The effort can be characterized as speed/power in musculoaerobic endurance regime. A boxer's body composition is mesomorph type; however, their leg muscles is ectomorph type. Boxer's legs are slim built for very fast movements.

Boxers have a high neuromuscular adaptation. Their muscles are almost all the time tensed, ready for action, and the emotional state is always under a constant stress.

11.2.2 Objectives

After reading this section, you will be able to understand and do the following:

- Explain what kind of techniques are used more in boxing and why.
- Explain why the majority of K.O. happens against the opponent head and not against the opponent midsection (especially against the liver).
- Explain which kind of defense, such as blocking and/or evading, are used more and why.
- Explain why boxers use more circular type of techniques than linear type of techniques.

11.2.3 Biomechanical and Technicotactical Principles in Boxing

The biomechanical principles in boxing are similar to karate but there are significant differences when it is about the application of force/power and the use of distance. In boxing, the dominant tactic is the attack in any form.

Boxers always keep their CoM centered in their stance. Positions are high for the possibility of changing directions. Boxers are close to each other, unlike in karate where the distance is far bigger because the attack can be delivered with the leg. The defender keeps his lead shoulder high which is used simply to protect the face in case of an attack.

The defender not only blocks the different attacks but also uses the head by moving left and right and swinging all the time (bob and weave) to avoid the upcoming punches. In boxing, a stopping attack into the attacker's attack is seldom seen as opposed to karate.

How should the term "*stopping attack*" be understood? When an attacker delivers his attack, let us say a "jab," the defender can also deliver a jab or reverse punch (cross), but this stopping attack must be landed before the attacker's attack reaches his target. The reason for not having such a kind of stopping attack is that both offensive maneuvers reach the target approximately at the same time and both boxers can be K.O.ed or damaged.

In classical karate, the attacks or stopping attacks are always stopped before the target with 2–3 cm. In this case, there will be no significant bodily damage to any fighter.

In boxing, once an attack is delivered, the defender has two options: defend him or counterattack with the same vigor of the attacker. In other words, there is a permanent exchange of punches from both opponents.

The attacker has a little bit more options for tactics: The attacker first uses jabs that are executed with the front arm. This is done in order to find out the distance and the defender's reaction. The second option is to use a definite attack of a jab or even a one–two attack, which is usually a front arm punch followed by a reverse arm punch (cross).

This one–two attack can usually be continued with an uppercut or hook if the distance has been gained. Also, at the same time, with the one–two attack from the attacker, the defender can clench the attacker by embracing the attacker's arms or simply break the distance and then turn for a counterattack.

Most of the definitive K.O. attacks are executed from a closer distance and those are punches executed circularly, such as uppercut or hook. Boxers have very strong and resilient upper body muscles, especially their abdomen. Seldom is knocking out executed against the body, particularly against the liver. Most of the K.O.s happen against the head of the defender.

11.2.4 Styles and Techniques of Boxing

Before analyzing any technique, we will describe succinctly different fighting styles. Here are the different styles or better said approaches for attacking an opponent.

- *Inside-fighter* or *in-fighter* represents a boxer who likes to fight at a close range, advocating mostly hooks and uppercut attacks.
- *Outside-fighter* or *out-fighter* is the opposite of the in-fighter. This boxer tends to execute mostly jabs from a long distance. They are mostly like to have a good footwork to keep a distance convenient for them. Outside boxers are good technicians and they rather win by accumulating points than executing knock outs.
- *Brawler fighter* represents the toughness of a boxer. They are tough, hard hitters and make up their hitting repertoire usually for a single decisive punch.
- *Hybrid fighters* are those boxers who can combine the aforementioned styles. They are the typical boxer type.

In boxing, there are only four basic punching techniques. It is noticeable that there are right-handed and left-handed boxers and of course bilateral boxers. In boxers who are right handed, their left hand is the leading hand and standing with the left leg in front of their body.

The rear hand is always the stronger one and from that position comes the name right handed or left handed. *Here are the techniques:*

- *Jab*—The punch is executed with the front arm. Typically, the jab is the fastest and longest punch and is most often used; however, it is not the most effective because it has less power in it. There is no boxer who does not use the jab. By using the jab, the fighter can estimate the distance necessary for delivering the more devastating hook, uppercut, or reverse punch (cross).
- *Cross*—(Reverse punch named in karate) the punch executed in a straight line with the rear arm, which initially has been held at the chin level. When a punch (jab, cross) is executed, the boxer pulls back the other arm in front of the chin or even in front of the face for protection. This pulling back of the arm in karate or in Taekwondo is similar to pulling back the fist to the side of the body, particularly

above the belt of the karateka. This pulling back of the fist (arm) to the side of the karateka's hip gives more hip rotating effect, which increases the power delivery of the karateka.

At the time of delivery of the reverse punch, the hip and the shoulder rotate in order to deliver an extra power. A boxer advocates a total rotation of the shoulder, neglecting somewhat the hip rotation (see Section 11.1). The technique of the reverse punch is mostly used in combination such as the classical "one–two" (jab–cross).

- *Hook*—It is a semicircular punch that can be executed by the front or by the reverse arm. This punch is very powerful.
- *Uppercut*—This punch is also a semicircular punch executed mostly with the rear hand. It is executed as a vertical rising punch. When a jab is executed and is followed by a reverse arm hook, it represents the deadliest combination.

The following will describe the defensive techniques:

- *Slip*—It represents the body rotation that includes the torso, the shoulder, and even the head. This defense is excellent if the defender gets the right time. The attack can be lost with a minimal effort of the defender.
- *Bobbing* and *Weaving*—They include the head movements laterally and the sinking of the body into a lower position in order to avoid the attack. All boxers execute this maneuver. Some boxers are bobbing and weaving almost all the time even if no attack occurs. This maneuver of bobbing and weaving all the time can wear the boxers down by losing their endurance during the fight.
- *Parrying* and *Blocking*—In this defense, the boxer uses his arm to block an upcoming attack or deflect an attack by pushing the attacker's arm away. The difference between the parry and the block is the following:
    - *Parry*—deflect an attack. The deflection can be a hit against the opponent's forearm or simply a push away of the opponent's glove.
    - *Block*—stop or obstruct an attack. Stopping an attack by a block represents a very simple movement such as holding the forearm or the glove against the attacker's punching fist. In the blocking

defense, one should understand another typical defense, which is the "cover-up," where the boxer raises both forearms vertically upward and holds the gloves together protecting his face. In this defense, the boxer lowers his CoM and also covers the lower abdomen area with his elbows.

- *Clinching*—It is a kind of defense where the defender will embrace the opponent's arm to tie him down against any punches. It is against the boxing rule and usually the referee says "break" or stop and the fight will resume.

11.2.5 Biomechanical Analysis of the Techniques

The description of any attack technique in boxing is relatively simple and almost anyone in the world has an idea how these techniques are executed. Each attacking technique, however, will be succinctly described, emphasizing from the part of the attacker, the power, speed, energy, momentum, impulse, work, and so on. Defensive techniques will not be analyzed. These techniques have been described before.

11.2.5.1 Jab

The jab has been described succinctly earlier. Here, the author adds the following things: For the jab to be more effective (powerful), the attacker can lean his leading arm shoulder side forward or he can even move his front leg a little bit forward. With one of these movements the attacker gives an extra amount of force by using his shoulder more in the act of punching.

Using the shoulder mass more, the attacker will have a better momentum. In this kind of execution of a *jab*, the impulse will be less because the used velocity will take a longer time to be executed. The jab can be executed as a "snapping punch" or "pushing punch." For using a "snapping punch," the distance between the two boxers must be very short. In this case, the "jab" will be followed by a "cross" or any other attack with the other hand of the boxer.

Jab can be executed in many ways: stepping forward and jab, stepping back and jab, jab and stepping laterally left or right, jab with a circular motion with the leg during the execution, and so on.

11.2.5.2 Observation of Physical Properties

Before describing the jab, a few words about a boxer position is presented. Figure 11.16 demonstrates a left fighting position. Both arms are kept in

FIGURE 11.16 Fighting position.

front of the boxer and the leading arm's shoulder is raised a little bit higher for a better protection of the face.

Figure 11.17a demonstrates the beginning of the jab. It is important to specify that boxers do not care as much as karate athletes that the punching forearm should brush the boxer side (see Figure 11.17a).

Figure 11.16 shows a right-handed position and the black arrow on the right elbow indicates the direction of rising up of the elbow during punching. Figure 11.17a shows (left-handed position) the elbow position that does not stick to the side of the boxer, like in karate. The little circle at the right side of the boxer (Figure 11.17a) could indicate the position of the fist of a karateka at the beginning of the punch.

Observing and consulting many other fighting sports (MMA, Muai-Thai, kick boxing) and even shot putting indicates that *before a punch* to be *executed* a jab or cross, holding the punching elbow lateral and high at the shoulder level or at least at the chest level is more advantageous and more effective (more power can be delivered). The question is why more effective and advantageous? Here, this will be described:

By using the described punching technique in boxing, there are four major muscles beyond other auxiliary muscles that act in the following way:

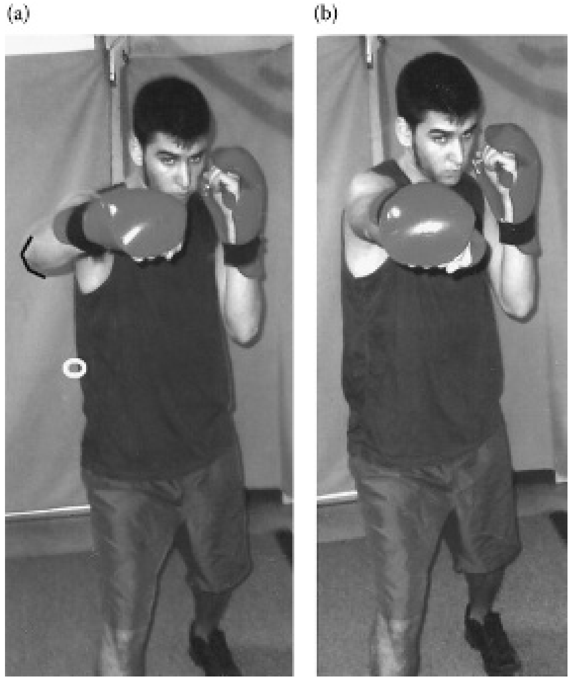


FIGURE 11.17 The technique of a jab.

1. *Pectoralis major* acts as a horizontal adductor and medial rotator of the *humerus*. The origin of the *clavicular head* acts as a flexor of the *humerus* bone. The origin of the *sternal head* extends the *humerus* from a flexed position.

2. The anterior part of the *deltoideus* is a horizontal adductor, flexor, and medial rotator of the *humerus*. The posterior part is an extensor and abductor of the *humerus* bone.

3. *Latissimus dorsi* is a powerful extensor of the flexed *humerus*. It adducts and medially rotates the *humerus*. However, the action is not conclusive when the arm and the forearm are in a horizontal position.

4. *Supraspinatus* abducts the *humerus* and stabilizes the head of the *humerus*.

By using the karate punch where the forearm must brush the side of the karateka in order for it to be effective, the author will describe the major muscles that contribute to the punching effectiveness:

1. *Latissimus dorsi* with its action as a medial rotator and adductor of the *humerus* is a real contributor for holding the forearm close to the side of the karateka.
2. *Teres major* acts as a medial rotator and adductor of the *humerus.*
3. *Rhomboid major* and *minor* are retractor or downward rotator of the scapula. By pulling the scapula toward the spine, these two muscles also assure the humerus to be close to the side of the body.

Earlier, it has been mentioned that even shot putters hold their flexed arm completely lateral at the horizontal level. More force can be delivered in this way. Imagine holding your fist at the side of your body above the pelvis and holding a 4 kg spherical weight in the fist. Try to push forward just as you want to punch forward. You will be amazed that by holding in this way the weight will not go far. When you hold the weight at the side of your neck and with your arm bent and held at the horizontal level, the weight will fly much further.

The reader now has the chance to realize which kind of punch is more effective! The word "advantageous" has been mentioned earlier. Punching like a karateka is quite difficult especially for a beginner because at the very beginning of the punching execution, the elbow will depart automatically from the side of the boxer or karateka and for this reason the instructor always insists telling the beginner to "keep your fist and forearm brushed at your side."

There are the following physical qualities: momentum, power, and energy. We will not describe any physical quality at this time; however, another good point for punching like a boxer is that the punch has not only linear but rotational execution because the swinging of the punching elbow goes far from the executor's body.

11.2.5.3 Cross (Reverse Punch)

Using a jab with the combination of the reverse punch represents the classical attacking technique in boxing. In order to be effective, by using a reverse punch in combination with a "jab," the level of attack must be different, for example, attack to the face with a "jab" and use a "cross" against the middle body section of the opponent. Changing the level of attack is very important because if both techniques go, for example, to the face, the second one (the cross) will be inefficient.

FIGURE 11.18 Execution of a cross (reverse punch).

If both attacks are delivered on the same level, then the defender will simply raise his forearms vertically and with this action he defends himself comfortably.

From the viewpoint of biomechanics the "cross" attack executed is more powerful than the "jab." In this technique, the boxer has a good chance to use his hip and shoulder power more efficiently.

Executing a "cross" punch requires the attacker to pull back and raise his leading fist to his face level for protection. Similar to karate, executing this technique and by withdrawing the opposite fist, the executing arm will be accelerated considerably.

In Figure 11.18a, the right-side boxer executes a jab that is blocked by the left-side boxer, then the right-side boxer will continue with a cross attack to the abdomen area (Figure 11.18b). In this figure, the rotation of the hip of the attacker can be clearly seen.

11.2.5.4 Observation of Physical Properties

The major physical quality is the power of the attacker. He can use not only the rotation of his hips but also the rotation of the shoulders. These two body parts with their rotation double the power of the attacker's punch. Besides executing a cross punch, the attacker should withdraw his right arm to his face; this movement is not shown in Figure 11.18b.

Most of the time when the cross is executed, at the final push, the rear foot heel is elevated and turned outside. In this way more hip rotation occurs. Let us calculate the power of the attacker: $(P) = \mathrm{N} \cdot \mathrm{m/s}$. Each boxer has 70 kg mass. Because the attacker uses almost his entire body

in the punching, the calculation will be for $P = [(m \cdot g)\ \mathrm{N}](\mathrm{m/s}) = (70\ \mathrm{kg})(9.8\ \mathrm{m/s^2}) = (686\ \mathrm{N}) \cdot (0.6\ \mathrm{m}/0.2\ \mathrm{s}) = 2058\ \mathrm{W}$ or J/s. The 0.2 s is an average velocity for the punching arm. The 0.6 m is the arm length. $KE = 1/2m.\ v^2 = 1/2\ (70\ \mathrm{kg})(0.2\ \mathrm{s})^2 = 1.4\ \mathrm{J}$.

Momentum $(p) = m \cdot v = (70\ \mathrm{kg})(3\ \mathrm{m/s}) = 210\ \mathrm{kg \cdot m/s}$. These calculations are valid only when the boxer does not hit a target. In our case, on hitting the abdomen, the value of the *KE* will change because of the dissipation of the energy and/or the longer contact time.

11.2.5.5 Hook

The punch executed with the technique of the "hook" is the most powerful and if this lands clearly on the opponent's face, then the punch will result in K.O. If the "hook" is executed with the leading (front) arm, the technique will be less efficient because the rotation of the shoulder and most importantly the hip rotation cannot be executed efficiently (Figure 11.19).

The rear arm "hook" is the most powerful. In this technique, the hip and the shoulder will turn comfortably, adding an extra power in the punch. The hook is also very dangerous physiologically because if the punch hits the jaw laterally by twisting the cervical spine, the effect will be a certain K.O.

The boxer who executes the hook is on the left and has a letter A on his back. Here, he executes a leading arm hook. During the execution of the hook, he protects his abdomen with his left elbow. This technique is very powerful. The angular velocity (ω) is high because of the rotational motion of the fist.

FIGURE 11.19 Boxer A executes a hook.

With this leading arm hook, the boxer tries to put more power in his execution by leading a little bit forward and turning as much as he can to rotate his right shoulder toward his left.

11.2.5.6 Observation of Physical Properties

Calculating angular velocity (ω) = rad/s. To calculate ω, we have to use the boxer's glove as a rotating reference point.

We also must have another fixed point that is supposed to be the axis of rotation, which we consider to be the right shoulder of the boxer. The punching arm starts with a 65° bent forearm over the upper arm, which could straighten a little bit at the end of the punch. This means that the upper and lower arms move in a compound motion—the upper arm rotates horizontally relative to the shoulder (assuming for simplicity that the body and shoulder do not move during the punch—a false assumption in most applications), and the lower arm rotates relative to the upper arm.

Lastly, it should be understood by having a straight line from the shoulder (axis) to the fist and this straight line represents the angle described by the punching fist. The angle described could be about 45° or 0.78 rad. The word *rotate* should not be confused with the twisting motion of the lower arm.

This is a 0.78 rad/0.11 s = ω = 7.09 rad/s. Angular acceleration (α) = rad/s^2 = 7.09^2 = 50.26. The 0.11 s is an average velocity. Calculating the moment of inertia cannot be done correctly for the following reasons: We do not know the exact punching route of the boxer because he can extend his forearm, increasing the distance between his forearm and upper arm or he can close this gap. For this reason, the distance from the shoulder to the fist is not exact.

If the distance is exact, then the moment of inertia can be calculated: $(I) = m \cdot r^2$. Calculating the angular kinetic energy, we encounter the same problem that we had by calculating the moment of inertia.

11.2.5.7 Uppercut

The uppercut can be executed to the chin and to the body area. It can be executed with the leading arm or with the rear arm. The effect is less compared with the punch of the hook. For any uppercut, the executor must bend his knees. He also must incline his upper body a little bit laterally. At the time of hitting, the knees will extend, giving the punch an extra pushing power from the knees. Executing the uppercut with the leading arm in combination is not advisable. To execute the uppercut with the rear arm,

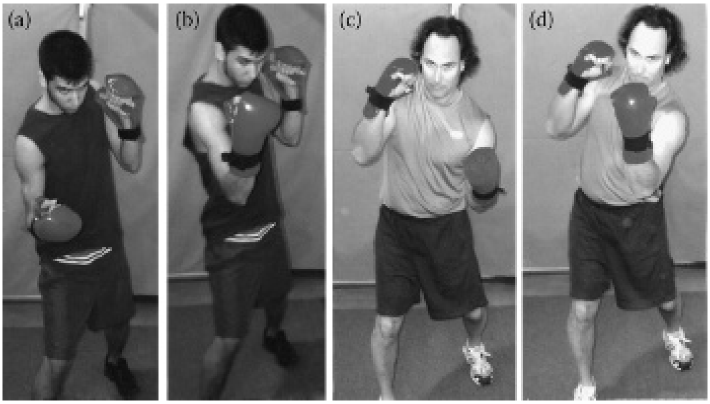


FIGURE 11.20 Various uppercuts.

the boxer must be as close to the opponent as possible to use a short jab, and then use the devastating uppercut to the stomach or to the chin area.

In order to be effective with the uppercut, the boxer must incline from the middle part of the body, a little bit laterally toward the hitting arm. After this movement, he should stabilize the nonhitting arm shoulder a little bit higher than the hitting arm shoulder. By this movement, the hitting arm shoulder will not be raised up instead of the entire upper body at the time of hitting, and by this, the hitting arm will deliver the necessary power for the uppercut.

When the boxer hits with the leading arm, both feet must be planted firmly on the ground. When the boxer hits with the rear arm, the rear leg ankle must be raised up for adding more force in the hitting and to make sure that the hitting arm hip can be rotated more. The figures demonstrate leading arm uppercut (Figure 11.20a and 11.20b). Figure 11.20c and 11.20d demonstrates the rear arm uppercut. All four figures demonstrate the high uppercut.

11.2.5.8 Observation of Physical Properties

This technique is somewhat similar to the hook. Both techniques employ a semicircular motion toward the target. However, there are some differences between the hook and the uppercut techniques and those are described below.

Recall that for calculating some physical properties, we established that the point of reference in the semicircular movement will be the boxer's glove and the axis of rotation will be the boxer's shoulder. Starting from this assumption, the hook will take a relatively round route approximately horizontal to the ground.

For the uppercut, the fist first descends, and then ascends in a vertical semicircular manner. For this reason, the kinetic energy will differ because the route is different. When the fist descends, gravity will be advantageous, and then when the fist ascends, the fist must work against gravity.

11.2.6 Biomechanical and Physiological Analysis of the Punching Technique Executed with the Boxing Glove and Bare Fist

Executing a punching attack with a boxing glove and with a bare fist will differ biomechanically and most importantly physiologically. Here are several important points to take into consideration, analyzing the effectiveness of these different punching attacks:

1. *Hitting* a *hard surface*, such as front or lateral of the jaw, temple or front part of the face (eye, nose, and/or lips).
2. *Hitting* a *soft surface*, such as chest, upper and/or lower ribs, abdomen, and liver.
3. *Ways* of *holding* the *punching forearm/fist*. Let us analyze each option.

1. *Hitting hard surface* with the *boxing glove* at the front of the jaw. The opponent will mostly have a physiological shock but this does not exclude obviously the shock as in pressure wave. Because the glove will cover a relatively large surface of the opponent that is why the shock wave travels far or better said expands.

During collision between two bodies (objects), there is a possibility of deformation of either bodies or one of the bodies. Bodies respond to collision in two ways: A collision in which the total kinetic energy after the collision remains the same for both bodies is called an *elastic collision*. For example, two balls (one billiard and the other one a tennis ball) can retain their original shape or recover their original shape.

A collision in which the total kinetic energy after the collision is less for one or for both bodies than before the collision is called an *inelastic collision*. In our case of boxing, when one opponent has been hit and gets a broken nose, then obviously there was an inelastic collision for the boxer with the broken nose.

During collision, there is a *coefficient of restitution* (e) or CoR, which indicates the impact resistance of the body. The value of the coefficients of the restitutions is between "1" and "0." The number "1" indicates a totally elastic collision and the "0" indicates a totally inelastic collision. In our

case, for the opponent who has been hit on his front jaw, the (*e*) for the punching fist at the time of contact will be less than "1" and probably will be close to 0.8 or 0.9. This is because the glove has been deformed for the moment. The (*e*) of 0.8 or 0.9 represents only an estimation.

It is true that we are interested not in the punching arm but in the punched jaw. Let us say the punched jaw has no deformation; this indicates a value (*e*) = 1. What these two values say to us? Because the punching fist with the glove has (*e*) = 0.8–0.9 indicates that the contact was less forceful than has been predicted. Obviously, the boxing glove will regain its original shape.

In the case of *hitting* with *bare fist*, obviously (with no jaw deformation) the value of (*e*) will be "1." Because the kinetic energy remains the same in this case, the punch is more devastating, having more energy deposited in the punched body (jaw) that could break the jaw of the opponent.

Having described these two possibilities by using gloves or bare fist, the reader could ask: which one is more effective to destroy an opponent by hitting the jaw? Here is the short explanation:

When a man got hit with the *boxing glove*, there will be temporarily less kinetic energy deposited into the system; however, the physiological shock is much greater than hitting with the bare fist. Hitting with the glove, the whole head will be shaken and for this reason, the brain suffers more than hitting with a bare fist. During a physiological shock, the peripheral blood flow is inadequate to provide sufficient oxygen for the heart and other vital organs. This shock can happen during a violent contact such as blow to a human.

On hitting the front part of the jaw with the *bare fist*, the following could happen:

a. The jaw could break because the kinetic energy is deposited into the first's two or three knuckles (which is a smaller area compared with a glove) and by this way the contact is extremely violent but the physiological shock will be less (and less damage for the brain), and thus the physical shock will prevail. There is no or adequately less shock if vital areas are not involved in the strike, especially when more receptive and conductive nerves are involved along with major arteries and veins.

b. On hitting with the bare fist, the person will have extreme pain, which is temporary, and most of the time, the person is ready to continue the fight.

On hitting the head's lateral side such as the jaw, temple, ear, and so on, the outcomes are totally different from the outcome of hitting the front part of the jaw. A few words about the different outcomes:

- The punch will have more acceleration because the execution is semicircular. Recall that velocity will be changed if the direction is changed. By changing the direction, the velocity changes into acceleration. By having more acceleration, the contact will be much harder and the result obviously will be more devastating.
- Taking in general view under the same umbrella, the side part of the head and face (ear, temple, and the mandible), the following can happen: ear drum rupture, broken and dislocated mandible, and the vagus nerve (auricular branch) affected during hitting the side of the head. The vagus nerve facilitates the parasympathetic nervous system, which causes a decreased heart rate, constriction of bronchioles, and constriction of coronary blood vessels.

2. On *hitting* a *soft surface* such as the chest or the abdomen (straight punch only) with the *boxing glove*, the outcome will be the following:

a. On hitting with the *boxing glove*, the collision will not reach the total elastic term. The stomach and/or the abdomen will be bent in the same token as the punching glove will suffers in an inelastic collision. Both the abdomen and the glove will have approximately a coefficient of collision about 0.8 for the boxing glove and 0.9 for the abdomen area. Using the boxing glove (because of its large surface), the kinetic energy will be less.

b. Hitting with the *bare fist* (straight punch only), the deposited kinetic energy from the fist into the abdomen could be more than the punch executed with the boxing glove because of the reduced area of the fist the punch has more penetration power.

The (e) of the abdomen will also be about 0.9 but the punching fist will keep the (e) 1 coefficient. The fist (e) = 1 will hold the penetration unchanged, so the damage with the bare fist will be more than the damage with the glove. Another general observation about hitting with bare fist or glove is as described below.

On hitting with the bare fist, the energy remains the same (transfer of energy) in the body; however, on hitting with the glove, the energy will be lost because the glove is bent at the time of contact.

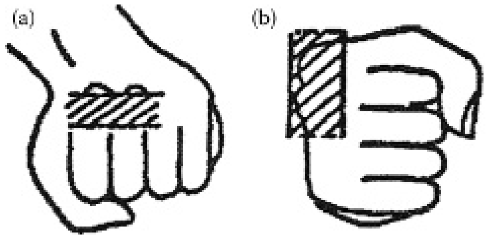


FIGURE 11.21

3. *Ways* of *holding* the *punching forearm/fist.* Because of the similarity between boxing and karate, we describe the karate "normal fist" hitting position in Japanese *(Seiken).* This position is similar to the boxing fist position.

Fold all the phalanges of the second to fifth fingers (proximal, middle, and distal) into your palm. The thumb will press on the middle phalange of the index and middle fingers. The fingers look downward and the attacking surface is the second and third head of the metacarpals (see Figure 11.21a) used in karate. In boxing, the attacking surface is the second, third, and fourth head of metacarpals. When the hitting position will be kept with the fingers looking downward, the radius bone is crossed a little bit over the ulna bone. If you hit a soft target, your fist can be bent at the wrist level because the two major bones cross each other. If the two bones are parallel to each other, the bending of the fist almost never occurs (Figure 11.21b). This position is known in karate as the "vertical fist" position in Japanese (*Tateken*).

These two positions are very important for the karateka. The boxers are not affected with this problem because their wrists are wrapped well all around with bandage to hold the fist with the forearm united like a spear position.

Figure 11.21a shows the normal fist (*Seiken*) where the radius bone crosses a little bit over the ulna bone.

Figure 11.21b shows the vertical fist (*Tateken*), where the radius bone is on the top of the forearm and the ulna bone is beneath and they are perfectly parallel with each other.

In engineering mechanics, if two or more steel lines are folded and twisted together, they are used for stretching. If two or more steel lines are parallel and not twisted together, they are used for compression. Compare your forearm and fist with a bridge construction.

CHAPTER 12

The Defense and Attack on Vital Points (Kyusho)

Finger(s) Manipulation

THIS BOOK DESCRIBES THE martial art—Vital Point (pressure point) practiced at present anywhere in the World. Kyusho-Jutsu started approximately at the end of the nineteenth century in Okinawa. At the beginning of the twentieth century, it has been known as an excellent (probably complete) martial art used for self-defense.

Kyusho-Jutsu has three parts that are strongly interrelated. They are: *Tuite*, which means grabbing hand. It is an art of pressing, rubbing the pressure points, and twisting the musculoskeletal body parts, particularly the joints, to inflict pain. It is used in grappling situations.

Sticky-hands Jujutsu is similar to Tuite. It uses pressure points with twisting actions. The main purpose is to grab the attacker's last two fingers (pinkie and ring finger together) and create a basis for a torque. Once the defender has managed to grab firmly the opponent's two fingers or even just one finger, it is extremely difficult for the latter to liberate himself from this grabbing position because of the torque created by the defender. The word *Kyusho* can be translated to mean vital points or pressure points. Here, the main action is the striking techniques directed against the vital points.

Pressing (rubbing) or hitting vital points and vital areas of the human body during self-defense will simplify the defense against an attacker.

A *vital point* usually covers a very small area/point of a nerve (usually a sensory nerve), and artery, or vein. If a vital point that is pressed covers a nerve, it is usually accompanied by pain. If the vital point covers an artery or vein, blood occlusion could occur, which triggers dizziness accompanied by pain and the result will be fainting of the participant.

A *vital area* covers a small area of the body (not a small point), such as the chin, solar plexus, groin, kidneys, and so on; here, the defender does not press but rather hits on the middle of the area. Attacking the vital area can bring death to the opponent; all this depends on using different factors, such as the force of hitting, the particular vital area, the accuracy of hitting the area, and others.

The application of pressure on a certain vital point sometimes does not give the expected result by generating pain to the assailant. There are many reasons for this:

1. The defender or the attacker cannot find the exact point of application.
2. The defender or the attacker does not apply the correct technique.
3. The defender tightens his muscles at the area of the pressure point application.
4. During the pressure on the defender's or the attacker's limb is not immobilized correctly (the limb is moving).

Note: Comment about No. 3. Point of explanation: If the muscle is tightened, then the pressure and sometimes the rubbing action will not work, because in general the pressure point is deeper in the muscle and is not exactly on the top of the muscle. However, in this case, the striking on the pressure point will work and the assailant will fall down, being incapacitated. To date, the pressure point usage on a vital point has had limited application in biomechanics. However, pressure on a vital point or a strike on a vital area is the first action for applying a successful finger manipulation. This chapter should be understood as a synergy to many martial arts,

in that often controlling some subsystem (like vital points) that can set up and position an opponent prior to executing techniques.

Finger manipulation has a biomechanical value. The fingers can be used as levers to immobilize an attacker. Using finger manipulation (pulling, twisting, bending, and rolling a finger against his normal range of motion) can be an extremely effective self-defense method. Using pressure on vital points and using finger manipulation go hand in hand.

Usually, when the defender sees that he is overpowered by the attacker using a particular attacking Kyusho technique against his arm or fist, he simply tightens his fist. When the fist is tightened and the attacker tries to open it, the fist will be extremely difficult to open and he will lose time doing it. At the same time, the attacker can change his attack to a different technique. There are different methods to open a squeezed fist. One of them is as follows: The defender should rub the top of the hand (one of the hands) and press at the p.p. TW-3, the ulnar nerve of the dorsal branch, an area which can be rubbed energetically. In this case, the hand will open and the defender can apply a finger manipulation technique to overcome his opponent.

What the reader can learn from this art about the viewpoint of biomechanics is probably less compared to the martial art of *Karate*. However, a study of this martial art, the musculoskeletal anatomy, cardiovascular, pulmonary, and nervous system and some of the physical properties such as energy, force, mass, etc. is important. They are the part of this fighting art. The most important is the knowledge of the musculoskeletal anatomy and the nervous system.

Let us explain a very important observation about this art. The *Kyusho-Jutsu* practitioner (defender) can defend himself in any position using only one finger against the attacker; he can comfortably defend himself, because it is possible for him to use the pressure points (361 in the human body) against the opponent, regardless of how the defender is facing the opponent, whether he is in a standing or supine position. The only exception to this rule is when the defender is in the prone position and he is immobilized by having the attacker on his back, perhaps holding one of the defender's arm in an immobilized position.

What is the importance of knowing well the human anatomy, especially the musculoskeletal system? Good knowledge of the muscular system is essential, as the person who will rub, press, hit the opponent

must ***visualize*** the pressure point site on the muscle. In this way, the mistake of striking the wrong site of the body part will happen seldom and the result of the strike will be effective. Another belief is that, at the time of striking or approximately 0.5 seconds before striking, you, the executor, must send your ***intention*** to the site and guide your mental energy to keep your intention 100% in order to succeed in your attack.

Prior to explaining a little bit about anatomy, we will start to explain the different roles of the physical properties. Let us elucidate what is a physical property? *A Physical property is any property that is measurable or observable. It shows/reflects any characteristics of an object/mass that can be measured or perceived without changing its identity.*

Probably the most important role has the *energy* and how to use it properly. Energy described in physics represents a system's ability to do work. The equation for potential energy $PE = m \cdot g \cdot h$; this is the equation for an object's gravitational potential energy, when an object *hypothetically* lifted up h = *distance* to a reference point, and g = represents the gravity. *See pages 147 and 148* for a better understanding of potential energy. Using your potential energy (your stored energy) basically has no physical explanation. This stored energy is something you or any human cannot see or, even more, cannot feel, whereas use of kinetic energy has a physical explanation. "The energy suggest a *dynamic state* related to a *condition of change* because the presence of energy is revealed only when a *change* has taken place." This concept is good only for kinetic energy. The kinetic energy equation $KE = ½\, m \cdot v^2$ where m = mass and v = velocity. It is used for linear KE.

Returning to potential energy, *a person knows* that he has energy because he can talk, eat, walk, etc., but he cannot explain his stored energy only when he does move. At this time, potential energy will turn into kinetic energy. However, the potential energy we say (Qi) can be liberated into the atmosphere, most importantly against your opponent.

The question for the stored energy is how it can be used (see the answer further on). Top masters of Kyusho-Jutsu, Chi masters, can use their stored energy. In the case for example you want your attacker to lose his consciousness by falling down or to be disoriented or even to be knocked out.

Here are a few words about the kinetic energy used in Kyusho-Jutsu, Qi-gong, Tai-chi, or Yoga, simply said, on how to use your potential

energy. The final purpose of using your potential (stored) energy is to destroy your opponent. How can you destroy your opponent if you do not know how to liberate your stored energy? There are some theories/facts according to Traditional Chinese Medicine (TCM). You know that if you extend your arm, there is kinetic energy involved. If you kick your opponent, he will feel pain or he will fall down. How can you direct/liberate a large amount of energy which definitively will hurt your opponent?

Here are some theories according to TCM. Logically, if you are a weak person and have lung disease or any other serious disease, you do not possess adequate energy which you can use to liberate into the outside World. Let us say you are a healthy person, but your energy is still not adequate; then the answer for you is to practice internal exercise which includes first concentration, then meditation. The author will not describe which kind of internal exercise practice; it could be Yoga, Tai Chi, Transcendental meditation or Qi Gong, etc. The more efficient internal type exercise for your internal energy is the practice of Qi Gong.

In the following, I will explain how you can use your internal energy for almost every action in your life and not necessarily understand the Traditional Chinese Medicine (TCM) concept. However, first, we use physics to explain the potential (stored) energy *(PE)*.

The equation of $PE = m \cdot g \cdot h$. $m = mass$, $g = gravity$, and $h = distance$. It is understandable that if you have a large amount of potential energy, you can direct the kinetic energy (simply means *energy*) efficiently. In this case, you do not have to move your body parts or walk, etc.; you just recognize that you have a movable energy. The word *kinein* is a Greek word meaning move. You may ask where is the force which is always present in any movement is. Here is the answer about the force. The force is a physical quality which can initiate any movement within the human body or a defined system. The force which starts within the body itself or between a systems of body's named *internal forces*.

When a force or forces initiate any movement outside of the specified body, it is named *external forces*. Inside the human body, the acting force starts with the contraction of the muscles. The contraction mechanism is the neuron (nerve cell), which is the functional unit of the nervous system. A neuron can initiate the conduction of impulses. These

impulses are initiated by electrical connections to the nervous system. The contraction of the nerves and its conduction of the impulses are manipulated by *action potential*. We will not describe the action potential because it was described in Chapter 5 under Movement Control (Muscular Physiology).

Let us return to the release mechanism of potential energy. According to TCM, the human body is electrically bipolar and it also has *energy (Qi) pathways* or *energy meridians*. Using these energy meridians is the key to liberating the potential energy to the outside World. It is well known that if you get hit, rubbed by a different mean electric current, simple strike then your body reacts accordingly, you will have a tremor, dizziness, and lose your balance, lose your consciousness, or even fall down. Your body will conduct your energy to the outside World or even from one meridian to another or from one organ to another in your body.

Your internal energy (Qi) could be so strong that you can send energy to an opponent without coming into contact with him.

Let us turn our attention to the energy meridians. There are 12 paired (Qi) meridians. The meridians coincide with the nervous pathways. The author will not describe the function of each of the Qi meridians. Short mention will be made of those 12 meridians. They are the lung (LU), pericardium (PC), heart (HT), large intestine (LI), triple warmer (TW), small intestine (SI), stomach (ST), gall bladder (GB), urinary bladder (BL), spleen (SP), liver (LV), and kidney (KI). There are other two major meridian channel not paired and those are the conception vessel (CV) and governing vessel (GV). All these meridians and vessels are interconnected, having a direct or indirect connection to each other. We will not describe the actions of these meridians. The reader can ask *where the energy conducting channel is*. In order to inflict pain, the person who executes the actions (striking, rubbing, etc.) will use one or two of the 361 acupuncture points to come into contact with and, of course, inflict pain.

To resume about the kinetic energy, the practitioner/attacker will use the *energy pathway communication channel*, which in fact are the impulse carrying *nerve fibers*. Nerves conduct afferent impulses from receptor organs toward the spinal cord and brain and impulses toward the effector organs. It is easy to understand why the nervous system,

is the key communication area in fact, is the energy pathway. Think logically for example: If you think—the brain is who assist or help to follow through your actions or if you want to speak, then again the nervous paths enter in function and if you want to use your energy, force, momentum etc. then again the nervous system will be that which will guide you into action and so on. The cardiovascular and pulmonary systems have their importance. Thanks to human sophisticated guiding coordination to function normally it is the main system, which is the CNS who will guide us in everyday activities including Kyusho-Jutsu (vital point art) function. The reader should know that besides touching, striking, rubbing the vital points, and inflicting pain on the attacker, the pressure point also has a positive side for healing. In this book, the healing method will not be described.

When we speak about the *cardiovascular* and *pulmonary* systems, we should think of them as a *secondary system* when we use the pressure point approach. What this means is that there are no direct pressure points on the cardiovascular and pulmonary systems; the pressure points as described earlier are to be found only on the nervous system. By hitting, let us say, a spot on a vein or an artery very close to a real pressure point site, the effect can be fatal immediately, which could affect the lung if the blood vessel has a thrombus (blocked) blood vessel. In this case, we speak about the cardiovascular/pulmonary system not as secondary, but as primary due to the extremely life threatening situation.

To resume about how to send your energy outside your body, it is done by daily practice of Qi-gong with correct concentration about your Qi, and then with correct meditation about your Qi.

In our present time, the Traditional Western Medicine (TWM) recognizes and uses successfully different types of meditation which combine the soft, slow movement to guide your internal energy.

Do not forget that your brain has the ultimate and unlimited/leading and guiding potential about anything that you would like to do in your life, including the guidance of your potential energy and furthermore your life expectancy.

On the following four pages will be demonstrated *Kokyu-Ryoku* (Arm liberation) or *Finger play* techniques. Since the movements/techniques are extremely sophisticated to describe, the author has decided to show these techniques only by photos.

Photo 1

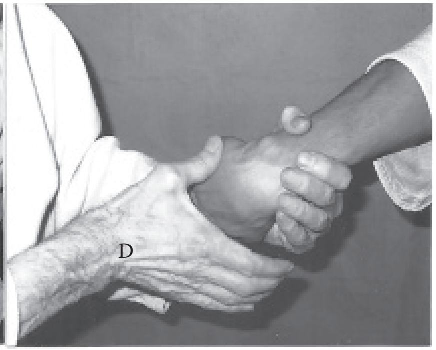


Photo 2

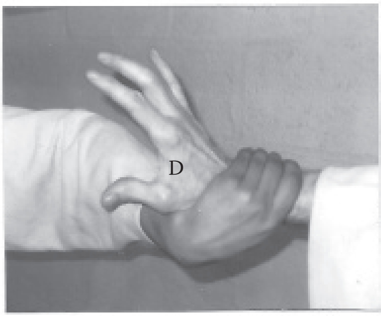


Photo 3

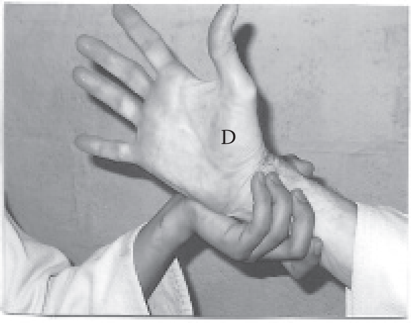


Photo 4

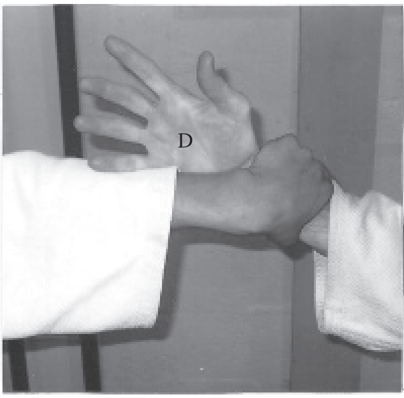


Photo 5

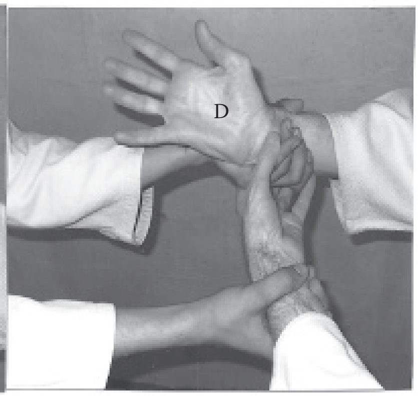
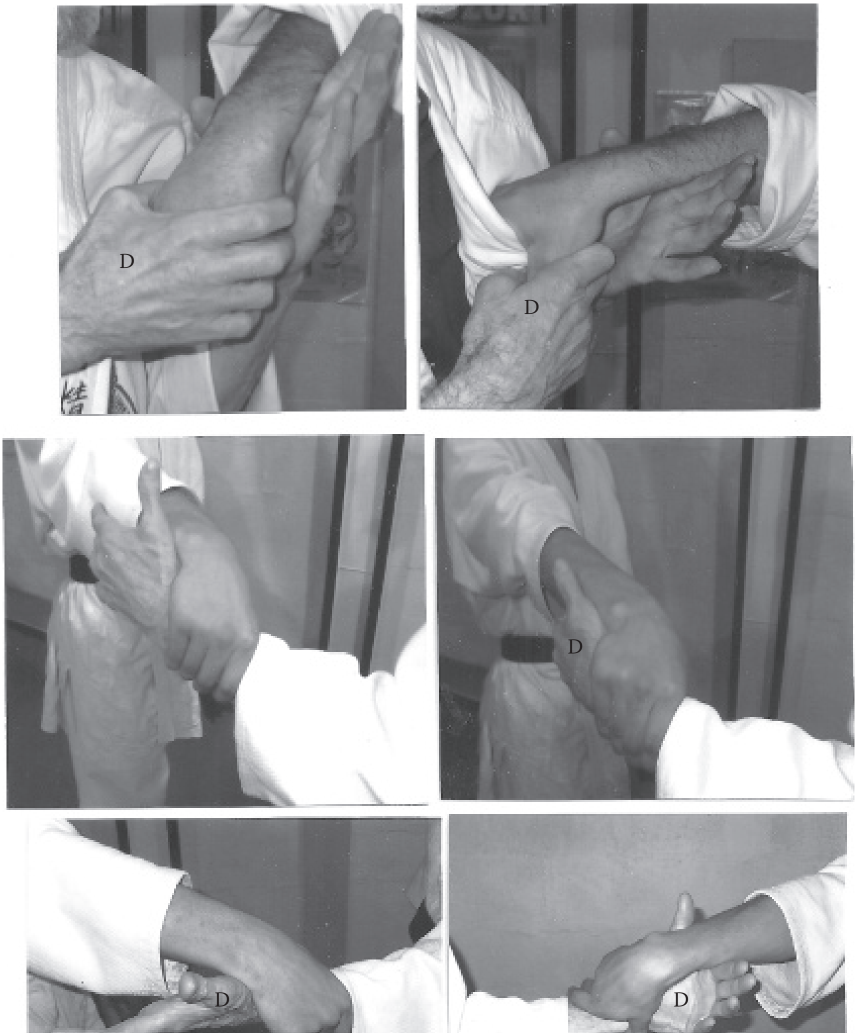
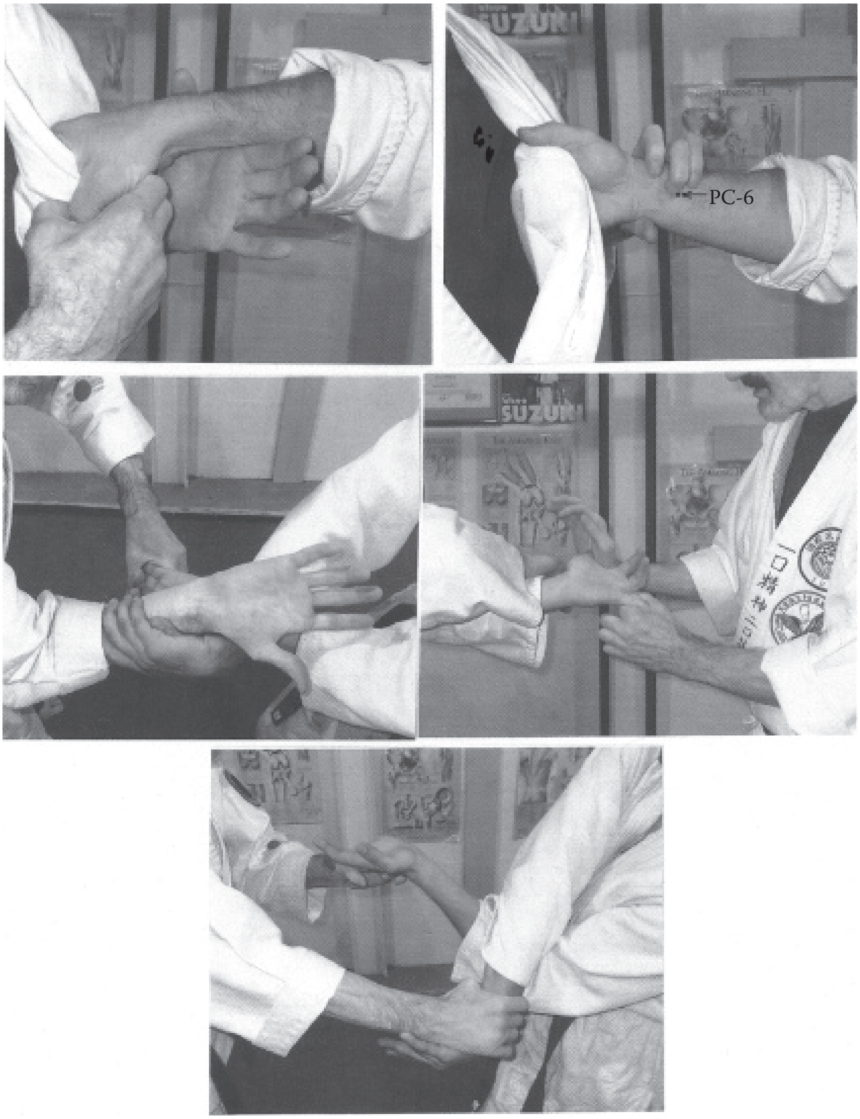


Photo 6

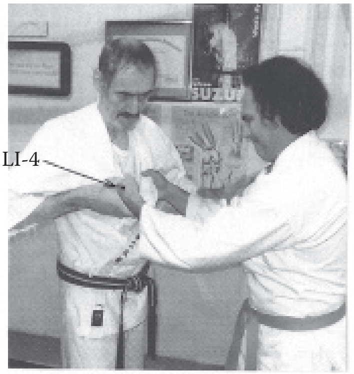
Note: The letter "D" means defender. In Photo 1, the attacker initially grabbed the defender's wrist, and the defender managed to re-grab the attacker's wrist.

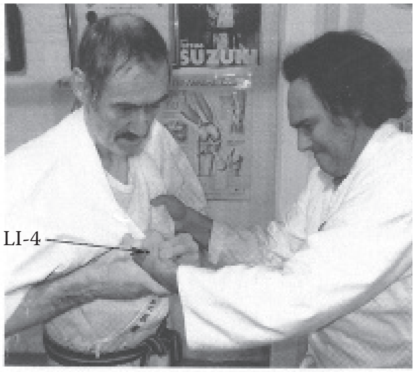
Other modalities to use the *Kokyu-Ryoku* (arm liberation) technique





Note: *Kokyu Ryoku* Aikido techniques for liberation against wrist grabbing. The defender can use p.p. techniques too. The top right photo uses the pericardium (PC-6). Pressure point.



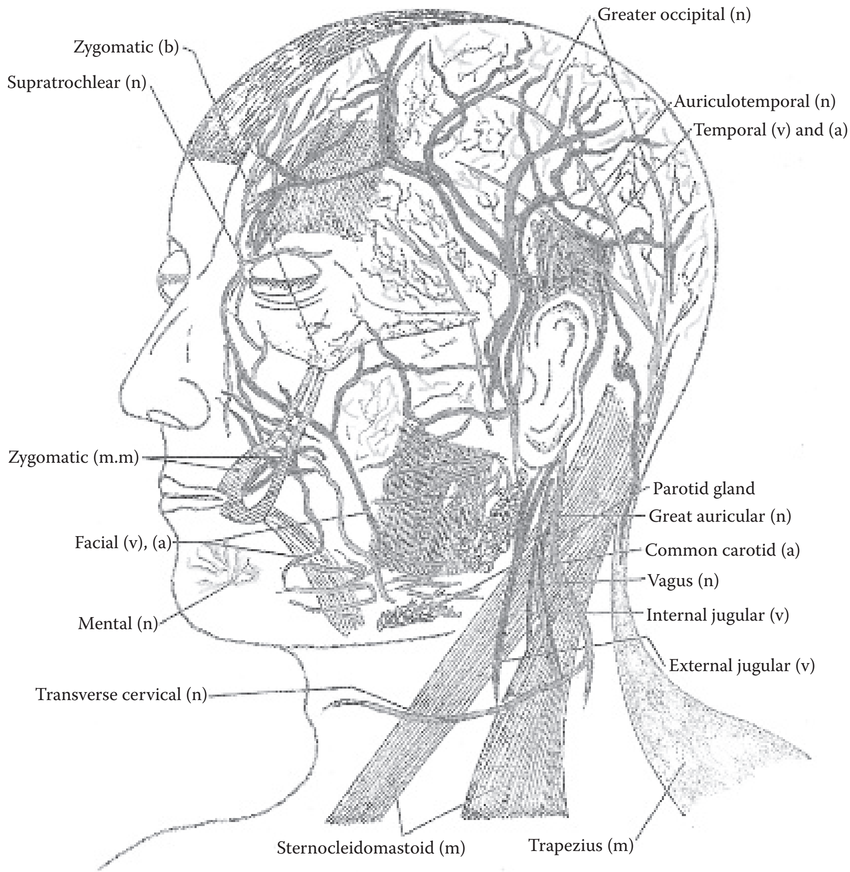


Note: The defender uses the p.p. LI – 4 (see the top photos) in the Sticky-hands Jujutsu style or in Tuite-Jutsu.

In the following pages, a few drawings will show the major arteries, veins, and nerves. The few black dots indicate pressure points but do not show the meridian channels.

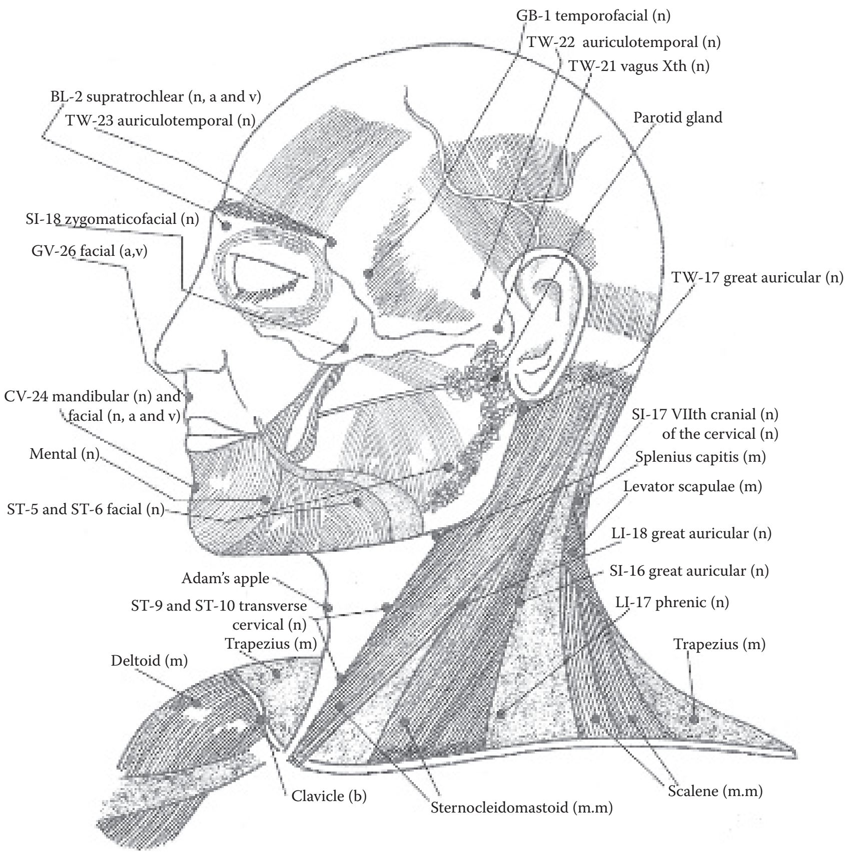
The following eight (8) anatomical (partial) charts give an idea to the Kyusho-jutsu participant not only about the anatomy muscular part per se, but also the nerves, arteries, and veins.

The Anatomy of the head and neck (the major arteries, veins and nerves)
The skin removed from the left side of the head and neck

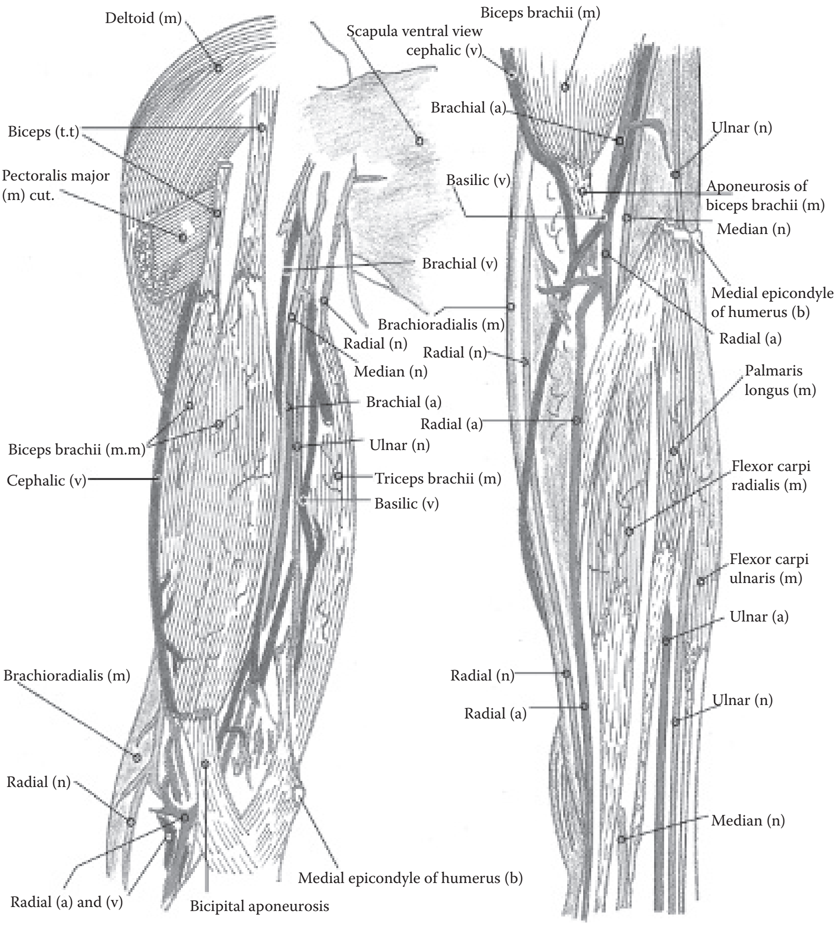


Note: The common carotid artery, vagus nerve, and internal jugular vein (part of it) are covered by the sternocleidomastoid muscle.

The major p.p. sites of the head and the neck (side view)



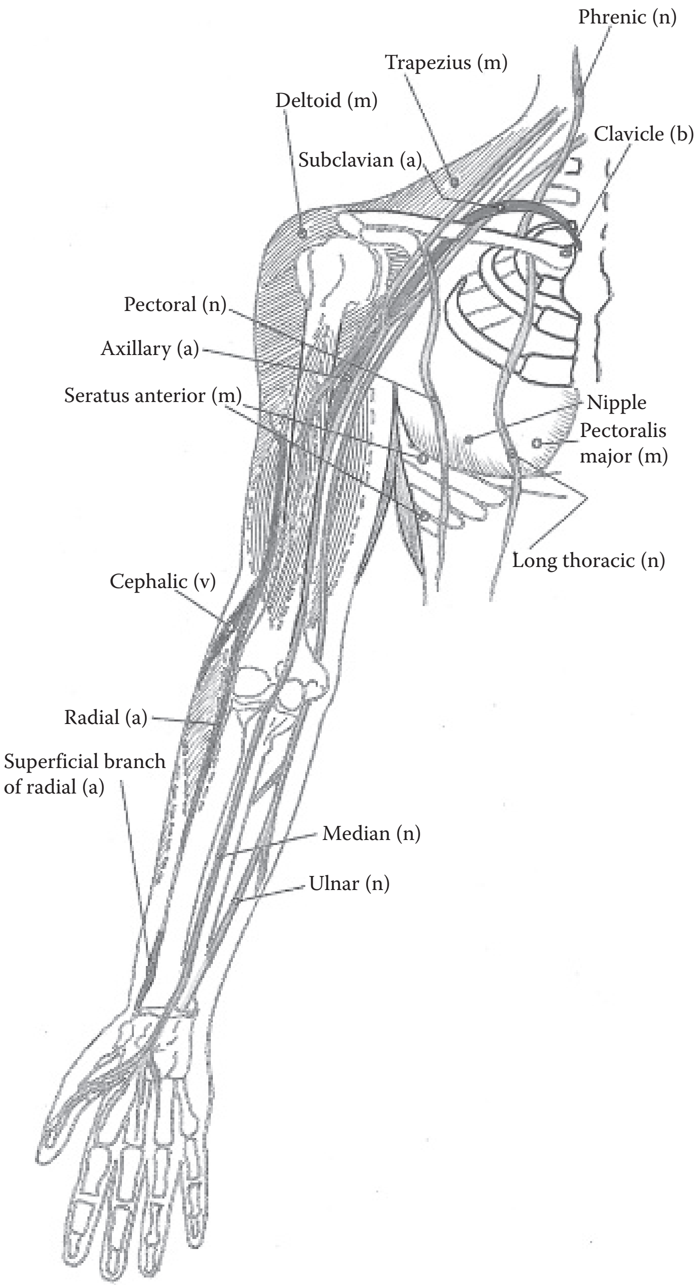
The anatomy of the arm, subcutaneous region (the major arteries, veins, and nerves)



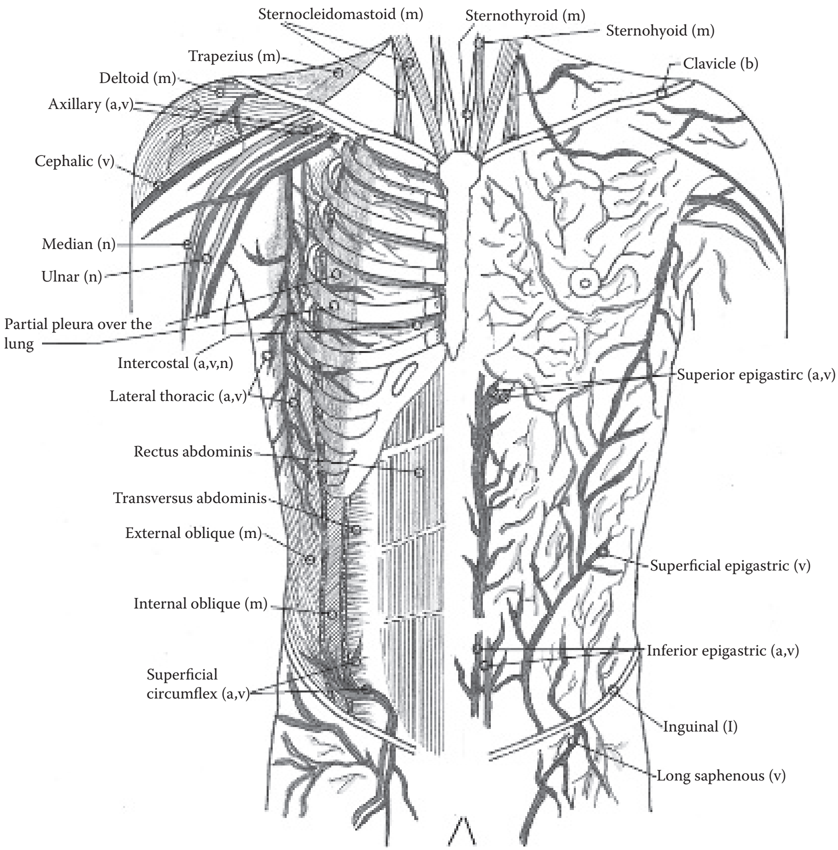
The *right arm* and the elbow pit
(Ventral aspect)

The *right forearm*
(Ventral view)

Major nerves of the arm from the Brachial plexus (above and under the clavicle and including the axilla region)

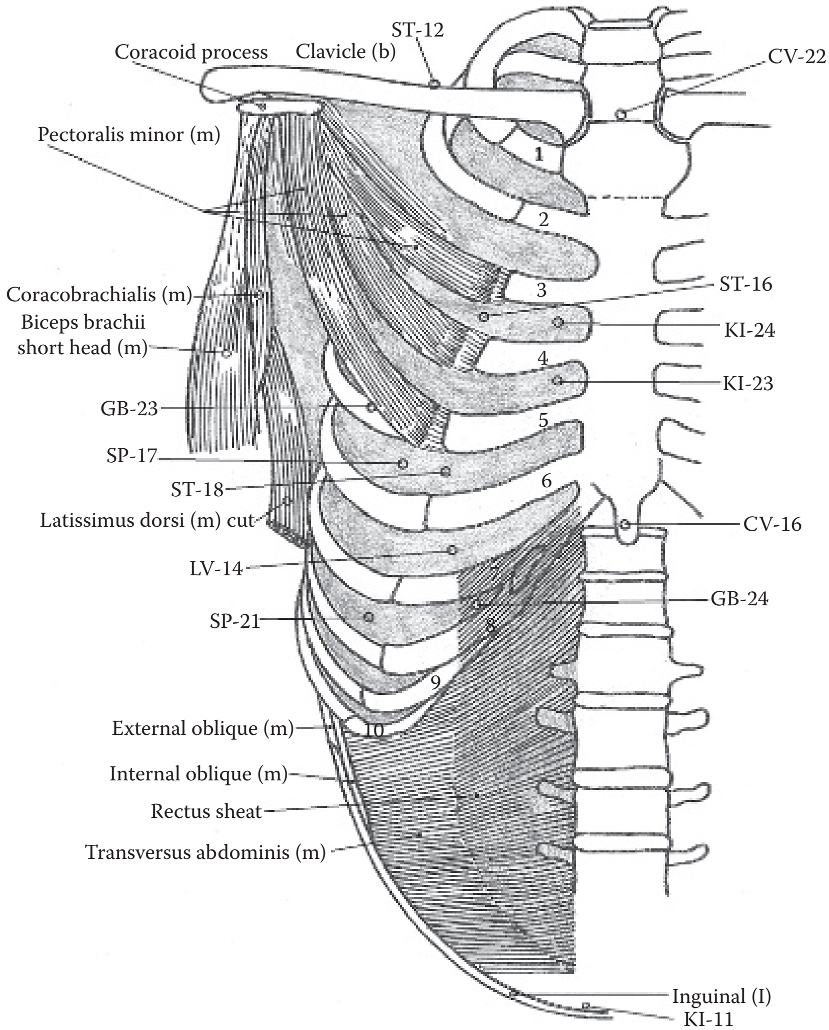


The anatomy of the thorax and abdomen (subcutaneous layer)



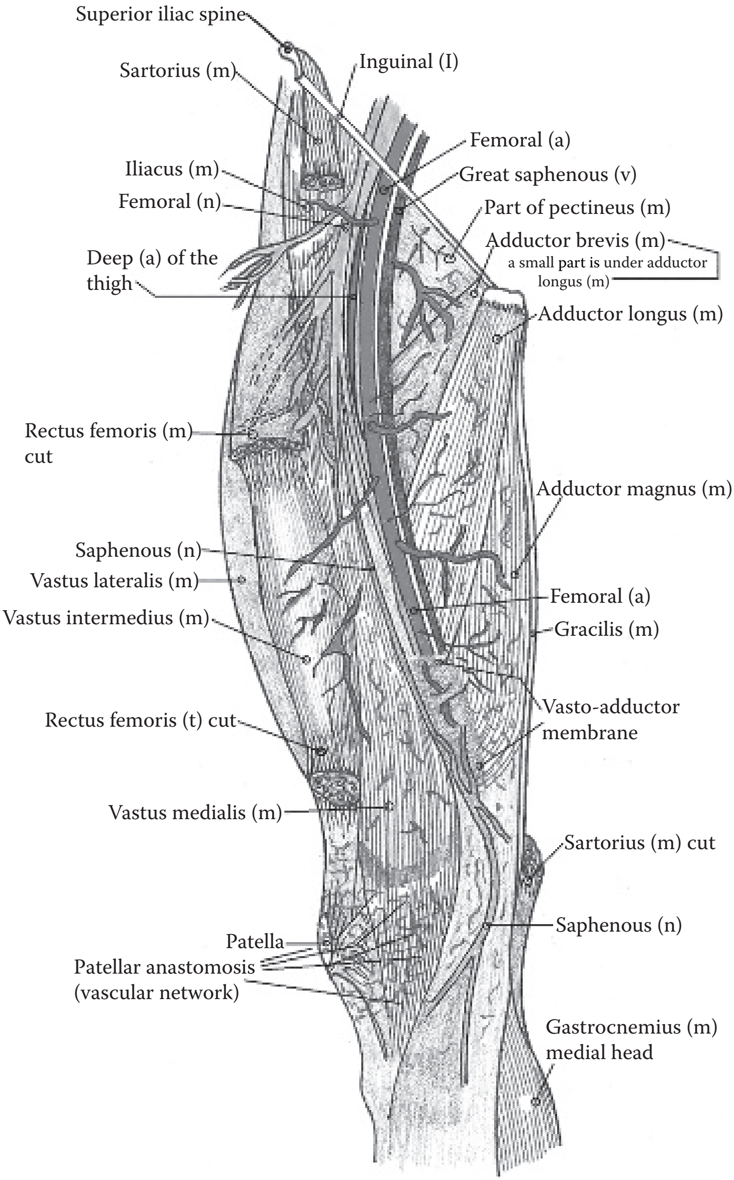
Note: The rectus abdominis and the transversus abdominis are muscles. There is no indication about the (m).

Trunk pressure point sites (stomach, gall bladder, spleen, liver, kidney and conception vessel)



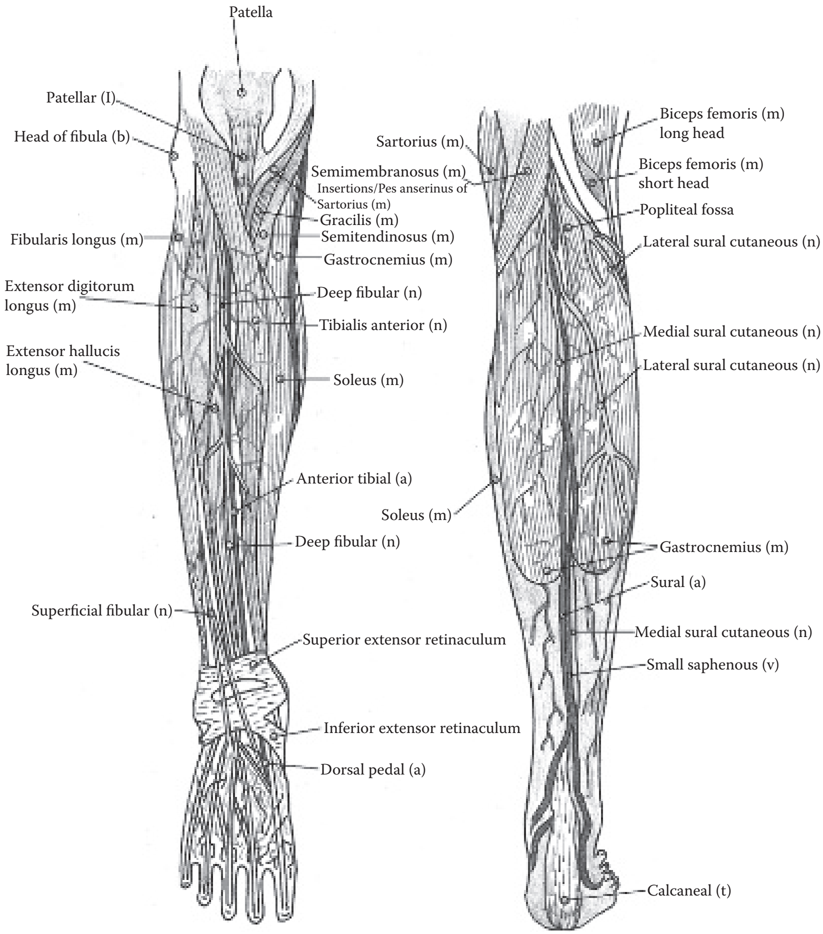
Note: The drawing represents some of the pressure points most often used. The reader can see that the majority of the p.p.'s are between the ribs where the innervations are. This anatomical site does not show many of the internal organs. The muscle of serratus anterior is not represented. The skin with pleura is removed. Consult the descriptions of the p.p.'s described earlier. Ventral aspect.

The anatomy of the thigh (the major arteries, veins, and nerves)



Note: The interrupted lines of the nerves show that they are under the rectus femoris (m). Ventral-medial aspect of the right thigh.

The anatomy of the leg (the major arteries, veins, and nerves)



Frontal aspect of the right leg *Dorsal aspect of the right leg*

In the following several pages will be shown *finger manipulation* with a *real opponent* and its pertinent explanation. The figures do not show how the defender reached the position shown.

In Figure 12.1a the defender first uses the *Kokyu-ryoku* hand liberation technique described in Section 10.8.1 from Aikido, and then will grab the attacker's ring finger and the pinkie to pull and to roll up against normal anatomical movement (the end of range of motion) of those fingers (forcing exaggerated extension) see (Figure 12.1b and c). Figure 12.1d shows a pressure point defense on the radial artery. Under the radial artery is the

FIGURE 12.1 Finger manipulation (*Kokyu-ryoku*).

FIGURE 12.2 Pressure point on the radial artery.

FIGURE 12.3 Pressure point defense.

LU-8 p.p. of the radial nerve. See the left side figure which uses the middle finger to press on p. point LU-8, which covers the radial artery, and under the artery is the radial nerve.

Figure 12.2 shows a defense after managing to grab the attacker's arm the Uke will press at the p.p. LU-5. Figure 12.3 shows a pressure point SP-11 for immobilizing the attacker after a successful take-down. Figure 12.4 shows defense against two hands grabbing.

12.1 BIOMECHANICAL ANALYSIS OF THE TECHNIQUES

12.1.1 Defense against Two Hands Grabbing

Both combatants stand with their right leg in front of their body (Figure 12.4a). The attacker is on the left side of the figures. The attacker grabs the right forearm of the defender. The defender executes a

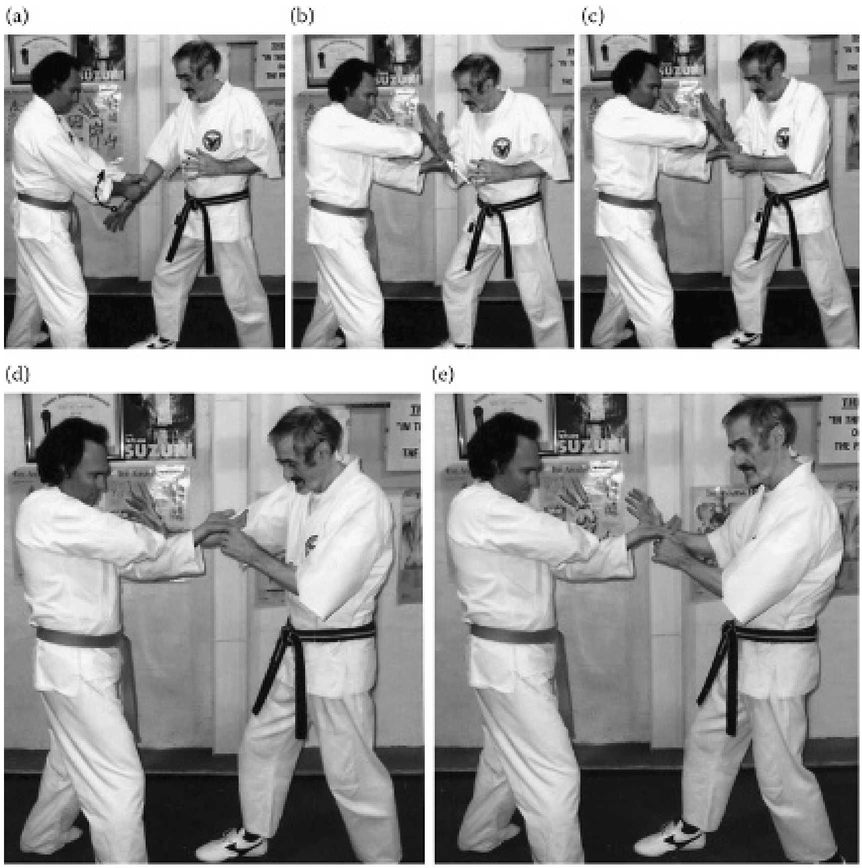


FIGURE 12.4 Defense against two hands grabbing.

Kokyu-ryoku (hand maneuver) by turning his right arm wrist upward and to his right. By this movement, he has the opportunity to grab the attacker's pinkie and/or the ring fingers together (Figure 12.4b and c).

The defender uses the attacker's two fingers as a lever for action. The defender now presses down the two fingers with his left hand and liberates his right forearm (Figure 12.4d). In Figure 12.4e, the defender pushes the attacker's thumb. In order to be successful, the action of pressing down the two fingers has to be performed in the following way:

The defender's left forefinger has to be held straight horizontally pointing to the right of the defender, and set directly under the pinkie and the ring finger of the attacker exactly between the two metacarpals and the two proximal phalanges of those fingers. With this action, the defender lifts (pushes) up his forefinger.

Meanwhile, the defender's thumb should be situated approximately in the middle phalanges of those fifth and fourth fingers. Once these maneuvers are done correctly, the defender can push down the attacker's fingers with his left-hand thumb. If the defender's thumb will be set on the distal phalanges, he can lose the contact because of the slipperiness of his thumb. Also, if the thumb is set on the proximal phalanges, the attacker has the chance to close his fist and grab the defender's thumb and counterattack.

Note: Many techniques described in this chapter are from "Sticky-hands Combat Jujutsu Style." This style highly emphasizes pressure point attacks and finger manipulation. In this style, there is no need for body dropping or throwing techniques. Everything is about the limb (hands, fingers, arms, legs) manipulation accompanied by pressure on vital points all over the human body. In the finger manipulation technique, the fine motor skill is the major technical element, which dictates successful finalization of the technique.

12.1.1.1 Observation of Physical Properties

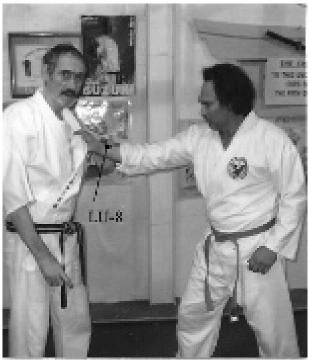
In this technique, the movements are reduced just for the forearm twisting action. There is not much to describe about physical properties. Rather, the motor qualities prevail, such as the strength of the attacker and the skill of the defender. To execute correctly the lever arm handling is extremely important for the defender to be successful in his defense.

12.1.2 Defense against One Arm, Front Collar Grabbing

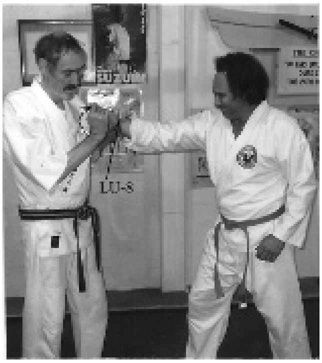
In this defense, the defender will use one pressure point and one finger manipulation technique. The attacker holds his right leg in a forward

position while the defender has his left leg in front. The attacker grabs the defender's collar with his right hand (Figure a).

(a)



(b)



(c)

Figure a and b shows how the defender uses a pressure point defense (see the tiny black circle), indicating the position where his left-hand middle finger tip should press the radial artery. It is a pressure point on the radial nerve (LU-8). However, on the top of the radial nerve is the radial artery. It is a dangerous point, as repeated pressure on this point will cause severe dizziness.

The right hand of the defender surrounds the attacker's thumb and forces the attacker to release the grip on the *Kimono* (Figure b). The black discontinuous semicircle line shows that the defender must push the attacker's thumb. In Figure c, the defender managed to pull the attacker's hand from the *Kimono* and continue his pressing on the attacker's thumb.

In Figure d, the arrow indicates the left hand of the defender. The defender will grab the attacker's pinkie and ring fingers together. In Figure e, the arrow indicates the action of the defender's fingers. From this position, the defender can force the attacker to be on his knees if his fingers are pressed down.

(d)

(e)

12.1.2.1 Observation of Physical Properties

This technique is very similar to the previous one. The difference is about the manipulation of the fingers, especially the thumb. In order to understand the defender's thumb manipulation, it is important to explain how to finish this technique. Let us start from the thumb's normal anatomical position, where the four fingers are aligned close to each other and the thumb is in proximity to the index finger. There are different modalities:

1. If the fist is closed and the thumb's distal phalange is closed on the index finger middle phalange, then the thumb can be forced backward (toward the dorsal part of the hand). Here is how to proceed: Maintain/hold the fist closed with your right palm; the other hand will push the thumb backward. This maneuver is not the best because the defender has the chance to rotate his fist and then escape.
2. Imagine that the fingers are closed or are aligned. The executor will attack the thumb in such a way that the thumb will be forced to scroll/close with its pinkie digital phalange toward the thenar eminence of the palm. There are two more modalities, which will not be described here.

Earlier, I stated that finger manipulation is a part of mechanics, especially concerning leverage. Finger manipulation is all about the lever of the finger attacked, and finally how it is maintained in a certain position suitable for defense.

12.1.3 Defense against Double Collar Grabbing

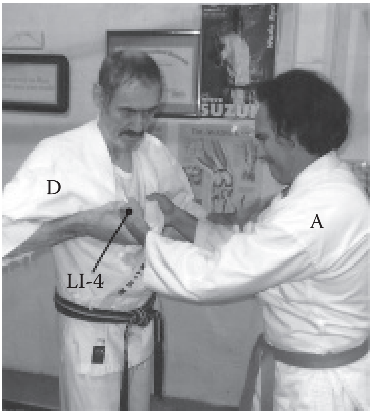
In this technique, the author will show another vital point pressure technique. Keep in mind that when you are attacked with both arms (grabbed in our case), pushed, or pulled, the defender's role is easier. Why is this? The simple reason is that both arms of the attacker are busy. He cannot use a free arm for hitting or even defending himself.

The defender must always concentrate on attacking or liberating *only one arm* of the attacker. Both the attacker and the defender stand with their right leg forward. Basically, it does not matter which leg is forward. The defender is denoted by letter D. The attacker is denoted by letter A. The following pressure point technique is extremely painful, and it does not matter how strongly the lapels are grabbed. If the technique is executed correctly, the attacker will open his fist from the grabbing position. As a

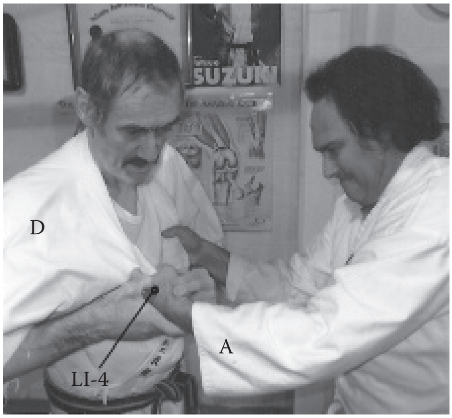
general example, a defender with a 70 kg mass can easily defend himself against an attacker with a 100 kg mass or even more.

In all the figures, the defender is on the left side. The attacker grabs both front lapels of the defender with both hands (Figure a). The defender will defend and attack the attacker's left hand. In Figure b, the defender's right thumb applies a vital point pressure on the attacker at the thumb proximal metacarpal base and the index finger metacarpal base. It is where the two fingers (thumb and index finger) of the metacarpal joint are (see the black dot in Figure a).

(a)



(b)



To be successful with this technique, the defender must hold his thumb distal phalange straight vertical toward the joint (the p.p.). Also, an additional and extremely important point is that the pressure must be *oriented on/or toward the trapezoid bone* (which is at the very base of the index finger-metacarpal base), and not toward the trapezium bone, which is at the end of the proximal metacarpal of the thumb (Figure b); observe the black dot). Here, basically, the pressure will be on the branch of the dorsal digital nerves (of radial nerve), which comes down on the dorsal part of the hand and continues with the dorsal metacarpal arteries until the end of the index finger. The pain mostly comes from the pressure on the nerve; however, it is not conclusive. During the pressure on the vital point described, the defender's right hand manipulates the attacker's left thumb (see Figure b, the arrows).

In the Figure, the defender succeeds in taking off the attacker's left arm. Meanwhile the attacker still holds the defender's left collar with his right arm. The defender still holds the thumb of the attacker, and continues his defense by twisting the attacker's left palm counterclockwise of the attacker (see Figure c), the arrow that indicates the twisting of the palm).

The defender twists even more the attacker's left palm to the prone position by grabbing the attacker's pinkie and ring fingers (Figure d). Figure d shows the defender reaching out with his left hand. Figure e shows the possibility of grabbing the attacker's hand.

(c)

(d)

(e)

(f)

Once the defender grabs the attacker's dorsal part of his hand and assures the grabbing position on his two fingers, he can lift up the two fingers and push down the dorsal part of the hand, also helping by pushing with his right palm base at the end of the fingers (Figure f).

Now, it is a matter of time when the attacker will release his right hand from the collar grabbing position. If the pain on his left hand fingers is unsupportable, he will release his right arm from the grabbing position and try to counterattack.

12.1.3.1 Observation of Physical Properties

Let us debate the defender's defense and his physical property of strength. Once the defender starts to press toward the trapezoid bone, the attacker has a minimal chance to escape from the defender's pressure. Here is how to release from the defender's pressure;

1. The attacker loosens his grip momentarily and re-grabs the lapel. Also, during these movements, the attacker should twist his fist to his right. By doing so, the defender can lose his *Kyusho* point. In addition, the defender should pull his grip a little bit.
2. The attacker loosens his grip momentarily and re-grabs the lapel a little bit higher (not lower).

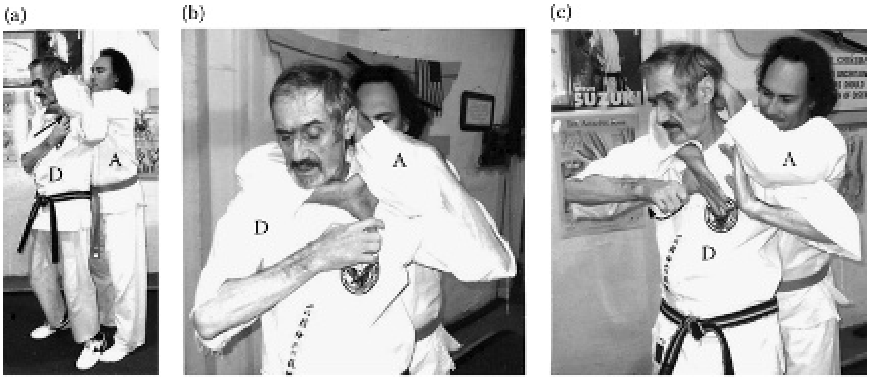
For the defender to be successful, the exact site of pressing on the vital points is crucial. Following the pressure on the vital point, the defender must be skillful to apply the correct leverage.

12.1.4 Defense against Rear Choking

This choking technique is not in the arsenal of the famous Kodokan Judo Institute (curriculum) of Japan. In Kodokan Judo, every choking technique has been taught by using the *Kimono* with one or two arms for choking the opponent. This technique is used without the *Kimono,* and can be done on the ground or when standing. The attacker only uses his bare hands for choking his opponent. Here is how it works:

The attacker stands behind the opponent. He surrounds the defender's neck with his right forearm and sets it on the opponent's front side of the neck. The attacker sets his left upper arm on the left shoulder of the opponent and then raises his forearm.

Now, the attacker sets his right open palm into his left elbow pit, and then moves his left palm on the back of the defender's neck. The choking action will occur by pulling backward the right forearm and pressing energetically his right palm into his left elbow pit and pushing forward the opponent's neck with his left palm (particularly with his knife hand portion). The attacker's right palm that is set into the left elbow pit is oriented with the thumb downward (Figure a and b). The defender defends himself as follows:

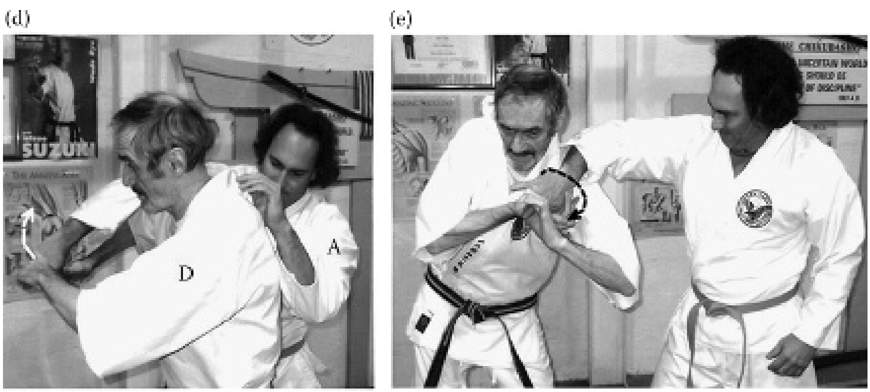


The defender will slide his right palm into the attacker's elbow pit until he finds the attacker's right-hand thumb. He grabs the attacker's thumb and pulls it out from the elbow pit position (Figure b).

The arrow in Figure c indicates the direction in which the thumb will be pulled by the defender.

Once the defender liberates himself from the choking position (it is a temporary liberation), he will grab the attacker's dorsal part of his hand with his left hand. Figure c shows the readiness of the defender's left palm for grabbing the attacker's dorsal part of his hand. The defender, having grabbed the attacker's right hand, turns toward his right at the same time and lifts the attacker's right arm up toward the right, which is also helped by the defender's right hand (Figure d).

In Figure d, the arrow indicates that the attacker's right arm will be raised circularly.



(f)

(g)

The defender raised up high the attacker's right arm will turn and step under the attacker's arm and will face him with his left side of the body (Figure e). In this position, the defender will twist the attacker's palm in such a way that it is held in a vertical position (Figure f).

The arrow in Figure f indicates the movement of the defender's left arm that is then pushed up forward. In this way, the attacker's palm is bent backward, which is painful. In Figure g, the defender's right palm is pushing the attacker's thumb (not shown).

12.1.4.1 Observation of Physical Properties

Many pressure points and finger manipulations have been demonstrated in previous techniques. This technique uses these as well. Both participants must be extremely knowledgeable. Anatomy is extremely important for the successful execution of these techniques.

It has been described earlier in this chapter that the martial artist deals with the leverage of the attacker's fingers. The reader will probably ask where the moment (resistance) arm is and where the force arm is in case of executing a torque. Obviously, each technical case is different: however, one thing is common: the defender deals with a very small area. Consequently, the force arm (FA) and resistance arm (RA) are very difficult to establish. Let us take as an example our last technique, "The Defense against Rear Choking."

First of all, we must also recognize the attacker's role and not just the defender's role. In Figure a and b, we can see that the attacker uses his right forearm as a lever, which in this case represents a force arm (FA). The fulcrum is represented by his elbow pit. Pushing forward the defender's head with his left forearm will represent the resistance arm (RA). This

leverage is considered to be a second class lever. This second class lever determination is relatively accurate even if the lever FA has relatively less freedom to move. In our case, the left palm of the attacker particularly represents the weight that works in conjunction with the gravity representing the RA.

It has been explained earlier that the determination of the leverage in martial arts is extremely difficult; furthermore, it can be even confusing.

For the sake of argument, if we reverse the roles of FA and RA but keep the fulcrum as the same spot, then the FA can be represented well and logically; however, the RA cannot because there is no weight that could represent the RA. (The weight in this case should be the right elbow of the attacker, but that elbow is almost totally unmovable.)

In martial arts generally and in our case, especially in the finger manipulation techniques, the fulcrum is not only movable in one point of the space but, most importantly, the fulcrum moves in multidimensional ways. Also, the fulcrum is changing almost all the time from one site to the other site of the body and also from one athlete to the other. So these facts should be kept in mind for establishing correct leverage.

Let us analyze the defender's role: Once the defender grabs the attacker's right thumb (Figure b and c), the defender has a lever, but what kind of lever does he have? Let us say that the *fulcrum* is represented by the *palmar* and *dorsal carpometacarpal ligaments* or the *distal radioulnar joint*. It is a simple lever having just the moment force arm (FA). Once the defender grabs the attacker's palm and twists, we cannot talk about lever arm per se. This is a twisted arm and we could rather talk momentarily about torque.

Looking at Figure f, we can again establish leverage. We can say that the *axis* is at the wrist of the attacker, and the lever arm (FA) is the total length of the palm of the attacker. The above described leverage about this technique can also be established for any other finger manipulation technique.

If a finger manipulation technique should occur when the defender and the attacker are on the ground, then the leverage can be established more precisely (see Section 10.4, Figure 10.18, and related explanations about leverage).

For those who are interested to know more about pressure (rubbing and/or hitting on vital points area), the author has described succinctly several vital points on the human body, their exact location, and their effect on the human body (see Appendix A) and more in this chapter.

Note: On the following pages, the author shows only two Kyusho-Jutsu (striking techniques).

12.1.5 Defense against Knife Attack (Kyusho Strike)

(a)

The Tori is on the left side of Figure a. He intends to stab the defender.

(b)

The p.p. technique is shown in Figure b. The Uke will hit the Tori's arm at p.p. LU-6 to his left (see the arrow) and the same time Uke will hit toward the right using his left palm. The knife will fall down due to a double hit on the attacker's hand.

(c)

Observe the dropped knife on the floor and the arrow for the attacker's right arm (Figure c).

12.1.5.1 Striking the Opponent's Face on Both Sides at Once

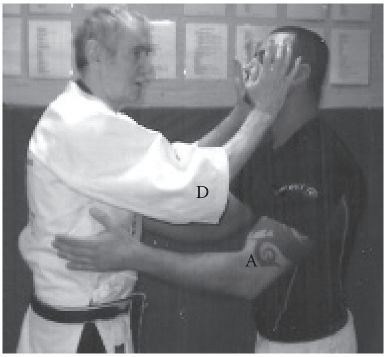
To strike the opponent's face on both sides at once, strike both LU-5 and LU-6.

(a)

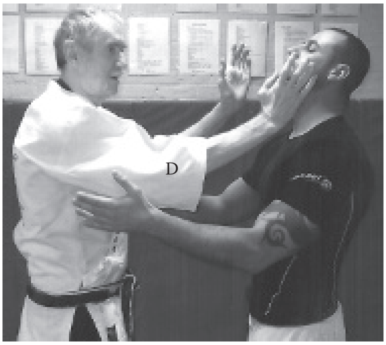
(b)

The attacker on the right tries to grab the defender's collar (Figure a). The defender pushes laterally and down against both arms of the attacker (Figure b).

(c)



(d)



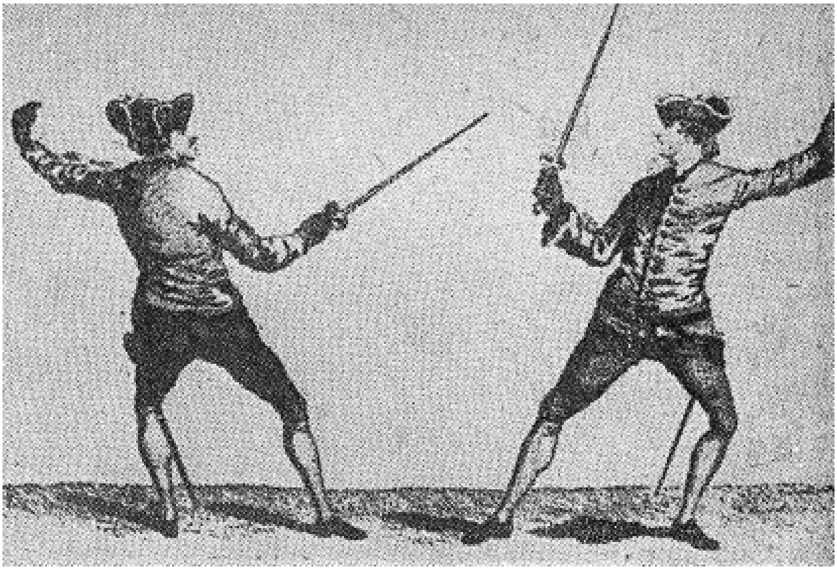
The defender continues his defense by striking with both palms at the attacker's ST-5 and ST-6 pressure points (Figures c and d).

12.2 CONCLUSION ABOUT VITAL POINT ART (KYUSHO-JUTSU)

Comparing Vital Point Art with any martial art such as Judo, Karate, Aikido, wrestling, etc., the author states that Kyusho-Jutsu is an art of precision. Knowing the totality of the physical properties, eye and hand coordination is the most important asset, including the energy and force that are the guiding properties and required by this art and its participant to be successful in defense or in attack.

CHAPTER 13

The Biomechanics of the Sword Art



Fencing around AD 1700.

Before describing the techniques used in fencing, it is important for the reader to know that the technical repertoire of fencing is as large as the karate technical repertoire. The major difference between these two arts is that the techniques in fencing competition are almost all the time combined with tactical solutions. In karate competition, the techniques

are executed giving priority to physical qualities (speed, power). For each weapon, 2–6 simple techniques and some combinations will be described, where most importantly the advantage of the levers will be described.

Fighting with long and heavy stick has been prevalent since human existence. At the time when bronze and later on iron was discovered, sword, halberd, epee, bayonet, and javelin have been used. These objects became weapons for defending a single human or an entire nation. Later on, approximately 2500 years ago, the sword became the principal weapon for fighting.

Fighting with sword became specialized for each nation. Also, the manufacturing process became very important for each nation. In ancient Japan, the sword (*Katana*) has been considered as the soul of the samurai. In Europe, a noble person without a sword was considered a nonentity.

13.1 MODERN (OLYMPIC) FENCING

Foil fencing: Close fencing bout.

Fencing in modern Olympic Games started from the year 1896. The weaponry has been much lighter than the usual fencing weapons used for dueling. The reason for using much lighter weapons was to eliminate the possible serious injuries during fencing.

At the first Olympic Games, only two weapons were used: foil and saber (or sabre). Later on, the epee, which is much heavier than the foil or the saber, was introduced. The international language for arbitrage, terminology of the techniques, and all other matters about the fencing sport are conducted in the French language. In this book, the author will use English, French, and Italian technical terminologies.

13.1.1 Anatomophysiological Considerations

Fencing movements in general are very much similar with karate. Automaticity of the technical executions and their combinations require long times of practice and many repetitions to learn the techniques in order to be successful during a fight. A fencer's body type is ectomorph, characterized with a "longilin," thin musculature. Fencers are usually tall

persons over 180 cm. It is also important to have an explosive power, but based on speed with a minimal time of execution.

Fencing competitions are time-consuming events. Many times a fencing competition starts at 9:00 a.m and finishes at 8:00–9:00 p.m. For this reason, fencers need to have a very good aerobic endurance in the speed regimen. Because of the accumulated long experience with long hours of fighting, fencers develop quite very large lung capacity, competing with swimmers, water polo players, and kayak/canoe athletes who are known to have the largest pulmonary capacity to retain oxygen.

The vital capacity for top fencers is about 6.5–7.2 L of air forcefully expelled after a maximal inspiration. The accumulation of the motor reaction time with the involuntary reflexes is quite extraordinary, due to the long hours spent during trainings and competitions.

13.1.1.1 Objectives

After reading this chapter, you will be able to understand and answer the following questions:

- Explain the advantages of step lunge and jumping lunge.
- What is the advantage/disadvantage of the "flying parry" in saber fencing?
- What is the advantage of the "thrown hit" (coupe hit) in foil fencing?
- Explain second intention attack and defense.
- Explain the difference between a feint and a false attack.
- Explain the difference between the words "parry" and "block."
- Describe in order of importance the most important physical/motor qualities in fencing.
- Explain if it is useful to use the guard for parrying in epee fencing.
- Which are the parts (any) of the blade to be used as lever and to create mechanical advantage?
- Which part of the blade is used to eliminate the opponent's blade (by pressing and sliding)?

13.1.1.2 Biomechanical and Technicotactical Principles in Fencing

Modern fencing is a real art. Fencing techniques executed extremely fast and combined with extremely fast thinking solve tactical solutions. Talking about thinking, which must happen in a fraction of a second, it is opposite to a chess game where you can take the time to solve your tactics.

Just like in any fighting art there are predetermined tactical solutions or better said prelearned technical combinations. In the art of fencing, the technical combinations are learned during fencing lessons with the fencing master. The tactical solutions are very rarely or can never be taught, but they can be explained by the instructor. There are many reasons for this:

1. Fencers think differently than a boxer or a karateka.
2. Fencers have different speeds of execution and reaction.
3. Fencers have styles (offensive, defensive).
4. Fencers use favorable different techniques in attack as well as in defense.
5. Many fencers use stopping attack.
6. Some fencers use second intention attack or second intention defense and others.

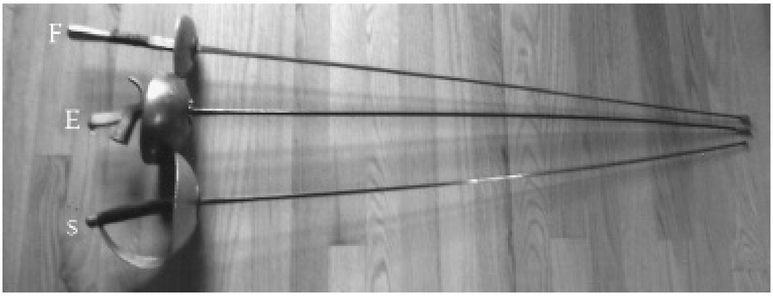
In fencing, speed is everything combined with great accuracy (especially in foil/epee), and skill is extremely important. In the biomechanics of fencing, we can calculate the speed, acceleration, kinetic energy, friction, angular velocity, moment of inertia, and even torque. Obviously there is a torque during the leg extension from flexion position during a lunge, but this torque is insignificant to be used for calculation.

For the weapon-held arm, there are angular movements involved, again for a very short time. In momentum calculation, the velocity is the most important. Impact force can be felt mostly in saber fencers.

13.1.2 Biomechanical Analysis of Techniques

Fencing has a multitude of techniques. The reader will not find many descriptions related to fencing. The author has selected and described techniques that are most significant from a biomechanics point of view.

13.1.2.1 Weapons, Target of the Body, Weapon Positions, and Foot Movements (Distancing)



The weapons—F is the French handle foil, E is the Belgian or pistol handle epee, and S is the saber.

13.1.2.1.1 The Weapons A weapon, be it foil, epee, or saber, has four parts: blade, guard, handle, and pommel (end of the handle) that keeps the weapon together. The handle of the foil and the epee have different shapes, such as French handle (straight); Belgian, pistol or orthopedic handle; and the Italian handle. The saber handles are gently curved and no other handle shape is used.

The length of the blade is 88–90 cm. The length from the guard to the end of the pommel, including the handle, is 18 cm. The blade for each weapon is theoretically divided into three parts with their significance in defense as well as in attack. The first third part of the weapon from the guard and close to the guard is used for defense, parrying.

The middle third of the blade is used for attacking the opponent blade such as beating, pressing, and sliding one's own blade on the opponent's blade to divert the direction of an eventual attack or to use beating away for own attack. The end third part of the blade closest to the tip of the blade is used to execute any attack such as thrust, cut, and slash.

Each weapon has different guards. We will not describe it here. The epee and the saber guards are larger because of the guard supposed to protect the fist of the attacker's arm.

13.1.2.1.2 Target of the Body The fencing mask has a cover part "bib" in front of the neck of the fencer; this is included as a valid target for all three weapons under the international competition rule. In the United States, local competition is not included. Valid targets for the foil are the upper body with the bib, including the full jacket under the black line.

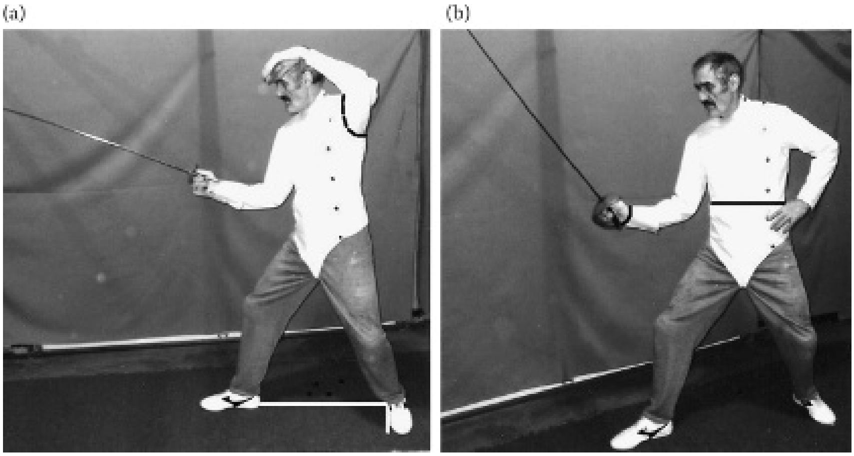


FIGURE 13.1 Target of the body: (a) foil and (b) saber.

The arms are completely excluded until the edge of the shoulder; the legs are excluded too (Figure 13.1a). The foil and epee fencers hold their free arm up as shown in Figure 13.1a. The target for epee includes the total body from the mask to the edge of the shoes and also including the gloves.

The target for saber includes the arms with the gloves; the body can be hit till the black line on the body (Figure 13.1b) and the mask with the bib. The saber fencers hold their free arm on their hips; legs are excluded. The body can be hit on the back too.

Fencers use a metallic jacket called a "lame." This lame is electrically wired. The fencers wear a long cord connected to the handle area of the weapon, which runs with a retractable reel that is, in turn, connected to the scoring machine. Each fencer has a colored bulb (usually red and green) on the machine that signals the scoring fencer on the valid area.

Figure 13.1a shows a very basic position of a foil or epee fencer. The position is the sixte that covers a higher right side of the fencer. The position of a fencer is shown in both figures. In Figure 13.1a, the white line indicates the two feet position opening a 90° angle. The longer line indicates the line connection of the two feet heels.

13.1.2.1.3 Weapon Positions In all three weapon systems, each weapon can be held in eight different (guard) positions. We will describe a few of the most used in combat. These are the weapon positions: first (prime), second (seconde), third (tierce), fourth (quarte), fifth (quinte), sixth (sixte),

seventh (septime), and eighth (octave). They are described in parentheses in Italian languages.

13.1.2.1.4 Foil and Epee Positions Figure 13.2a shows the sixte position. Figure 13.2b shows the quarte position. Figure 13.2c shows the seconde position. Figure 13.2d shows the octave position. Each position protects a certain body part. The reader can realize that the blade kept in a low position will protect the lower body part (from the abdomen level down until the groin and lower level for the epee).

There are some variations of these weapon positions. The blocking fist part of the weapon is dropped deeper instead of using the prime position.

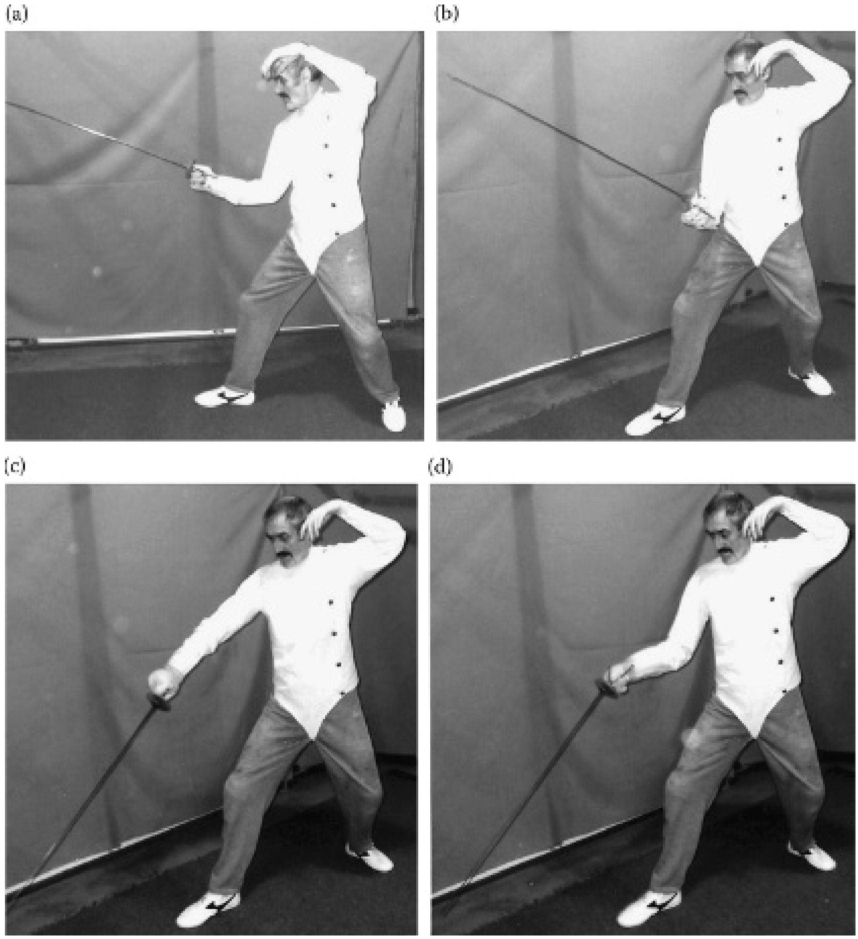


FIGURE 13.2 Foil and epee positions: (a) sixte, (b) quarte, (c) seconde, and (d) octave.

The most used position for attack is the sixte position. From this position, the fencer lunges straightforward. However, many fencers for tactical reasons or for their favorite positions use Figures 13.2c and d.

13.1.2.1.5 Saber Positions However, fencers are very aware about the positions described earlier. For example, from a lowered weapon in saber competitions, the fencer who holds down his weapon has a good chance to execute an arm cut. This cut is like a stopping attack *(stop cut)* under the weapon guard of the saber. Also, it is easy to execute a *stop thrust* attack in foil.

Figure 13.3a shows the prime position, Figure 13.3b shows seconde position, Figure 13.3c shows tierce position, Figure 13.3d shows the

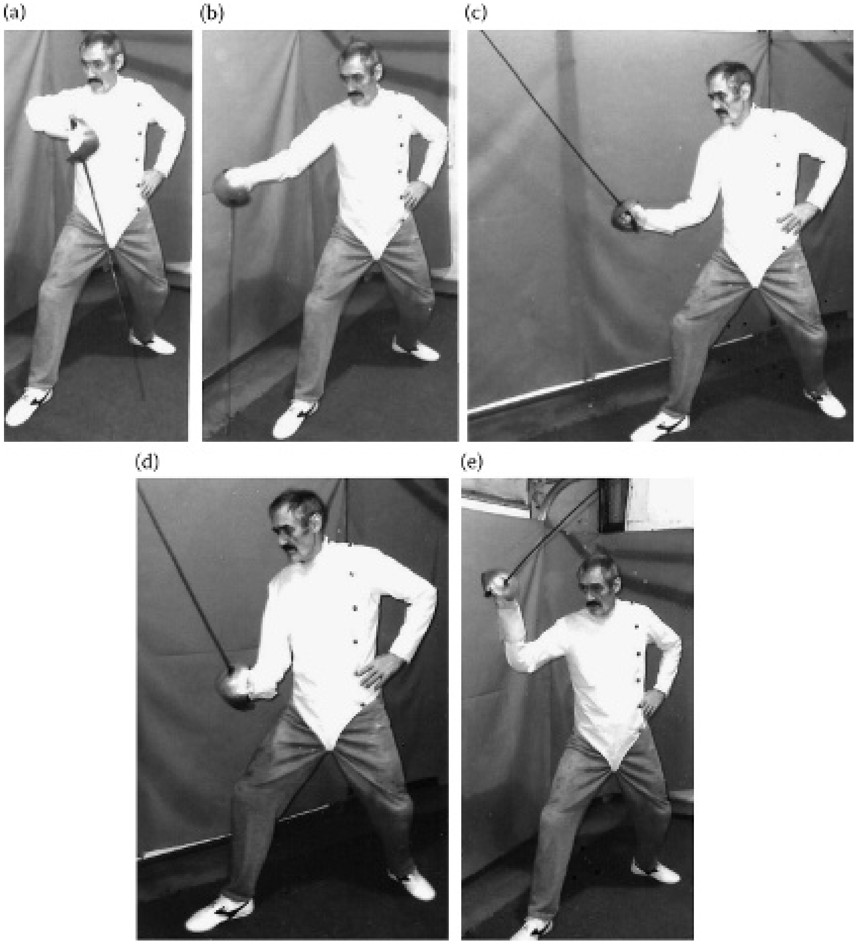


FIGURE 13.3 Saber positions: (a) prime, (b) seconde, (c) tierce, (d) quarte, and (e) quinte.

quarte position, and Figure 13.3e shows the quinte position of the saber weapon.

Obviously, the fencer can move the positions in any direction such as left, right, up, down, and circular. These positions, of course, depend on the line of attack. The most used positions are tierce and sometimes seconde positions. For tactical solutions, fencers somehow hold their weapons in a dropped position.

13.1.2.1.6 Foot Movements (Distancing) In fencing, there are several methods of leg movements for approaching or retreating from an opponent. The most obvious and similar ones are what we know as the *added leg stepping.*

Figure 13.1a shows the basic position named "En garde" or "On guard" (be ready) from which the fencer (right-handed) lifts up his right leg to move forward, and then he adds the left leg using the same distance for advancement. For example, the front leg will make a distance of ~20 cm, then the left leg will approach doing the same distance of 20 cm to be on guard again.

Another distancing is the *crossed leg stepping.* Use Figure 13.1a again as a basic on-guard starting position. The fencer will move forward with his left leg crossing over the right leg. Then the right leg will be moved forward to be in the same on-guard position.

The third type of distancing is the normal walking as you walk on the street. This stepping is seldom used in fencing.

Another way to approach the opponent is the *lunge*, which is the *basic attack in fencing.* From the basic on guard position, the fencer extends his right leg forward, then sets it down for balancing his body. The left leg remains completely extended (Figure 13.4a and 13.4b).

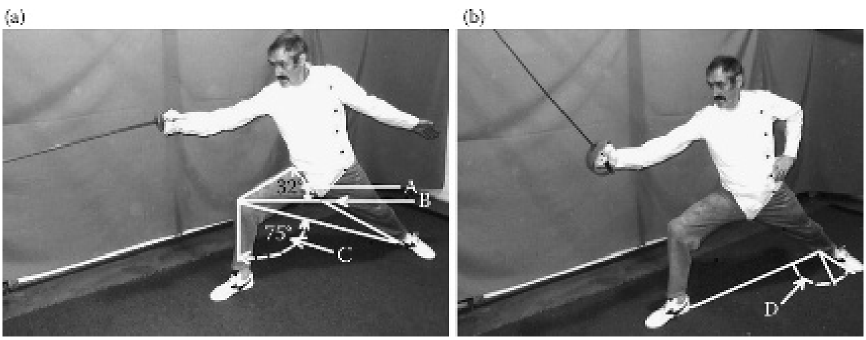


FIGURE 13.4 Execution of the lunge: (a) foil and (b) saber.

Figure 13.4a demonstrates a lunge executed by a foil fencer. Letter "A" indicates an angle of 32° between the top of the fencer thigh and the horizontal line. If the fencer is in this final position holding the 30–32° angles, then the lunge is not considered as the best technical execution.

If the thigh of the fencer is lower (parallel to the ground), which is noted with letter "B," it is considered as a correct lunge. Lowering the thigh to the level of 75° noted with letter "C" is considered as the best lunge position. The above represented figure is considered as a weak lunge position (demonstrated by the author).

Figure 13.4b demonstrates a lunge by a saber fencer. The lines indicate that in the final position, the attacking line (right foot) should hold a 90° angle with the left foot to be considered as a correct position. Theoretically, there are three distances between two fencers:

1. Short distance, where two fencers can hit each other simply extending the weapon-holding arm. This position is used exclusively in fencing hall (gym).
2. Medium distance, where both fencers can reach other with a simple lunge.
3. Long distance, where the fencer must execute a very fast short step followed by a lunge named *step lunge* (Patinando in Italian language or En marchant in French language).
4. Also, for long-distance attack, *a jump lunge* (Balestra in Italian language) is used. In this technique, the fencer executes a short jump forward from his initial en garde position to gain distance and then executes the lunge. This attack is extremely fast; however, it is pretty dangerous against those fencers who are versatile in stopping attack because the jump lunge is executed in two tempos. Between these two tempos is the opportunity to stop the attacker in good time. Numbers 3 and 4 are used all the time. See the explanation about tempo in Section 13.1.3.

There is another form of approaching your opponent: when you are in the lunge position and have almost reached your opponent, but you; however, miss by a very short distance (~10–15 cm), you can follow your opponent by adding your left leg in a forward position (en garde) and then execute another lunge. The name of this technique is raddopio or

redoublement in French language. A fencer can also retreat from an en garde position by simply jumping back in en garde position.

Another approaching movement is the *fleche* (meaning arrow in French), which is considered as an explosive, running attack used only in foil and epee fencing. The last way to approach the opponent is the *flunge*. It is a combination of a lunge and a fleche, which is used in saber fencing.

13.1.3 Biomechanical Analysis of the Attack and Defensive Techniques

In the following sections, the description of different techniques will not follow a logical and methodological path, simply because there is no reason to describe the simplest technique, which perhaps has some biomechanics value. When a certain technique is described and explained under biomechanical rules, some tactical solutions also will be described with that technique.

Recall that in the beginning of this chapter, it has been stated that in fencing the technical executions are strictly connected with tactical solutions more than in any other sports. That is why modern fencing is one of the most sophisticated sports to learn because the vast amount of techniques also includes vast amount of tactical solutions.

Before analyzing the attack and defensive techniques, we will describe some technical actions that strictly relate to tactical solutions:

1. "Blade in line" represents an outstretched arm with the weapon for a threatening reason.
2. "Beat" represents a sharp hit on the opponent's blade. This hit must have an extremely short duration. The reason to hit the opponent's blade is to move away from the line of attack of the opponent.
3. "Engagement" represents the contact between the fencers' weapons.
4. "Disengagement" represents evasive actions in which a fencer avoids the opponent's attempt to "engage" his blade. The disengagement mostly occurs with circular movements of the blade.
5. "Feint" is an apparent attack; however, it has to be executed as to create a reaction from the opponent. Usually the attacker moves his blade in line toward a body target (up, down, side, etc.), which should create

a reaction from the opponent by executing a parry; then the attacker executes a disengagement and hits the body target on the opposite side. The feint must be executed with a relatively slow motion.

6. "False attack" is also an apparent attack; however, the blade in motion for the false attack must be executed with a great deal of momentum (mass and velocity), with an apparent but false intention of hitting the opponent, but the attack will stop short of the target. We are not entering into a detailed explanation about "feint" and "false attack."

7. "Parry" usually represents a blocking maneuver against any attack (to be a thrust or cut). It is extremely important to explain the words "parry" and "blocking."

   According to the *Random House Dictionary*, parry represents a ward-off motion against a thrust as in fencing. In the author's opinion, this explanation is correct, especially in fencing with foil or epee where the attacks are straight. Basically, the parry is a soft and not a rigid motion.

8. "Blocking" represents a solid blockage against an intruder such as the cut from the saber. The blocking action must be executed with a very sharp and hard motion. In karate, the majority blocking actions are executed with a great force; however, soft blocks are also used in karate, but they never use the word parry.

9. "Remise" is a repeated attack immediately after the opponent parries an initial attack. It is executed in the same line of the initial attack or can be executed with disengagement.

10. "Coupe" (throwing hit) represents a kind of flying fishing movement, when the fisherman with a whipping motion throws his fishing rod with its bait. This technique is extremely effective.

    There are many other technical and tactical executions, which we will not describe here. However, the author would like to explain the difference between the words "Tempo" and "Rhythm." These two words are used interchangeable but in a confusing mode by many karate and some fencing instructors.

    "Rhythm" represents a temporal characteristic feature of a motor act consisting of the periodical accentuation, according to certain rules, of some of its constructive elements.

"Tempo of movement" represents a temporal characteristic feature of a motor act indicating its quantity of structural elements referred to the unity of time. Specifically, the word "tempo" in fencing is mostly called "psychological tempo." In simple words, it is expressed as the "time of shock." The fencer is unaware of the opponent's surprise action. In such a time of shock, everything is possible. The defender caught in this time of shock cannot use any parry or the attacker can use a surprise attack to score an unexpected hit against his opponent.

11. "Game of the weapons" (exchange blade positions) represents the engagement of the weapons, which includes hitting the opponent's blade, sliding, pushing and pressing away, or circling around the blade.

12. "Right-of-way" represents your right to score against an opponent who scores too, your right to a riposte at the same time with the attack. More explanations will be given later.

13.1.4 Attack and Defensive Techniques in Foil and Epee: Biomechanical Characteristics

The foil and epee are weapons used only for thrusting an opponent. Hitting or cuttings are allowed against the opponent blade for the purpose to push aside the weapon. In the following sections will describe the major differences between foil and epee fencing.

13.1.4.1 Particularities of Foil Fencing

This is a weapon of precision. The weapon is long, and to score a point, the only part used is the tip of the blade. Parrying the tip of the weapon of a novice is relatively easy; however, parrying an expert attack is very difficult for the following reasons:

1. The attack is extremely fast.

2. Seeing the tip of the blade is not easy.

3. The timing of the attack execution is usually very well done and for this reason the parry can be late.

4. The target of the human body is very large for a small tip.

Foil blade thickness is ~1/3 mm at the top of the blade. At the other end of the blade, which is at the guard, the thickness is 10×10 mm. The total

length of the foil is 1.05 m. Modern fencing signals a touch of the fencer by an electric apparatus with a red or green bulb that shows which opponent obtained a valid touch (hit). Along the blade is a narrow groove in which are glued two tiny wires. At the tip of the blade, a small button operates with a spring at the touch of the opponent.

If a green or red bulb lights, then it confirms that the correct area has been hit. If a white bulb lights, it means that a forbidden area has been hit. The foil is a conventional weapon. In fencing, "conventional" means traditional and there are certain very important rules about touches on the opponent. For example, if fencer (A) attacks with a correctly determined lunge and hits fencer (B) and at the same time fencer (B) hits fencer (A) with a stopping thrust, then fencer (B's) stopping attack will not be considered as a valid point (touch) giving the priority of fencer (A's) attack. In this case fencer (A) had the "right-of-way."

Foil fencing characteristics should be considered rather from a physiological and psychological point of view than from a biomechanical point of view. Having stated this, the major biomechanical aspect would be the speed of the participant guided by the reflex action and reaction of the fencer.

The kinetic energy enters into count after a long day of participation in a competition. Momentum is important, especially ignoring the mass and according importance for the velocity of the fencer. Impulse is negligible even if the contact time is extremely short; the force involved also is very minimal. Furthermore, the area of contact is extremely minuscule compared to the force involved.

13.1.4.2 Nr.1. Engagement, Attack, Parry, and Riposte

Fencer (A) is on the left side of the figure and attacks with a straight thrust from a basic en guarde position of sixte (Figure 13.5a). Fencer (B) on the right side parries with the position of quarte and ripostes also with the same straight attack (Figure 13.5b).

In this engagement, there is a simple exchange of speed. Considering purely the speed itself, fencer (A) could have a good momentum because he also uses his entire body mass, not only his speed. Fencer (B), the defender, also has almost the same momentum as fencer (A); however, his momentum is a little bit reduced in comparison to fencer (A) because he loses time executing a parry. After a parry, there could be a little hesitation about the target for using the riposte. Fencer (A) with 70 kg mass could have a velocity roughly 9 m/s, just like a black belt karateka punch. Fencer (A's) total momentum is $(p) = m \cdot v$ or (70 kg)(9 m/s) = 630 kg·m/s.

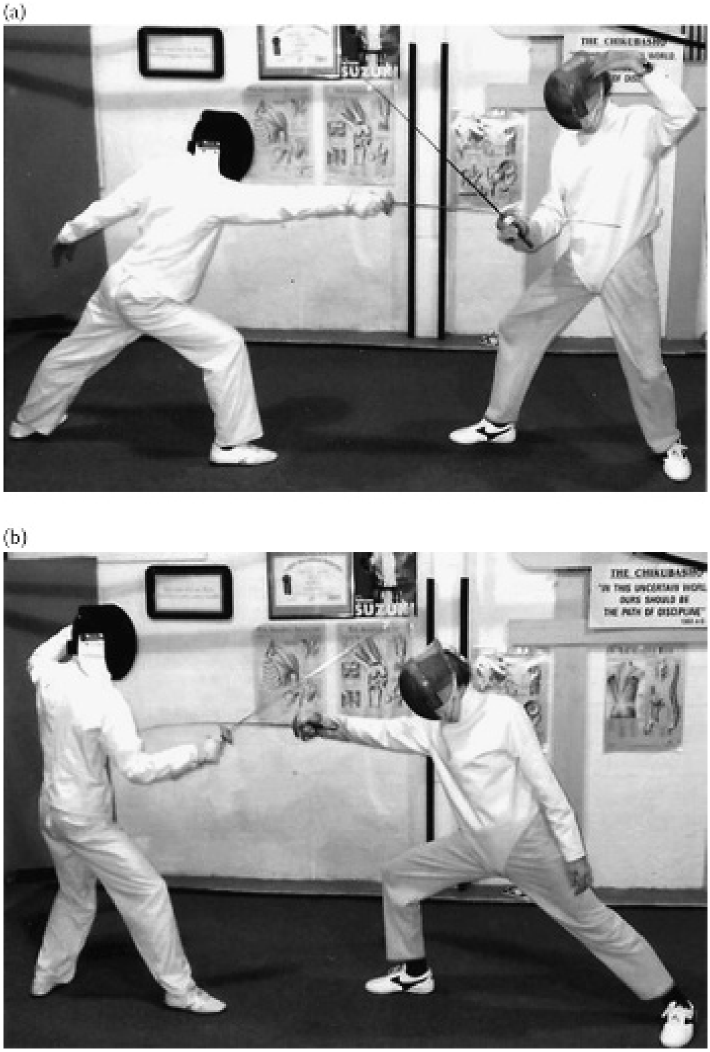


FIGURE 13.5 Engagement, attack, parry, and riposte.

13.1.4.3 Nr.2. Engagement, Parry, and Coupe Riposte with Lunge

This technique is used mostly by the highly skillful fencers. As previously described, this technique of hit/thrust is executed by a thrown motion. The fencer who executes this technique must be sure that during the execution of throwing, his hit will be before the opponent can execute a stopping thrust.

The attacker (A) is on the left side on each figure and executes a direct attack against the fencer (B). The attack executed by (A) is closed to the fencer (B's) sixte position. For this reason, (B) executes a counter sixte

(circular) parry, excluding the fencer (A's) blade toward (B's) right side. This parry is executed with a circular movement (Figure 13.6a) toward the right.

Fencer (A) recovers back into his original position of on guard. Fencer (B) pulls back (concentrating on his blade tip) his blade (Figure 13.6b, the black arrow indicates the movement) laterally toward his right side in such a way as to lose the contact on the opponent's blade. In this way, (B) has total control on his weapon's blade.

After (A) retreats and (B) controls his weapon, the throwing direction is indicated with a white arrow in Figure 13.6c. The letter "Y" indicates the approximate position of (B's) tip of the weapon. The "X" indicates the final touch of the coupe attack.

The coupe attack is the fastest in foil fencing. (A's) blade that is touching (B's) chest will not be considered as a valid hit if (B's) coupe riposte hits (A's) body first or at the same time. Hitting (A's) body at the same time with a counterattack, the coupe riposte has "right-of-way."

13.1.4.3.1 Observation of Physical Properties Analyzing (B's) riposte, we can conclude that besides a linear attack, fencer (B's) blade describes one circular and two semicircular movements. Those are as follows: The *first circular movement* occurs when (B) executes a complete circular parry of 360° (Figure 13.6a). The *second semicircular movement* occurs when (B) retreats his blade. This is a semicircular movement and the axis of this circular movement is the fencer (B's) wrist (Figure 13.6b). The *third semicircular movement* occurs when (B) starts to throw his tip of the blade toward the opponent's body and ends when his tip of the blade scores (Figure 13.6c).

To calculate the physical properties of all three circular motions, only the *tip of the blade is counted*, which describes the angles related to the *axis a straight line to the fencer B's wrist*. We have moment of inertia, torque, angular acceleration, power, and angular kinetic energy. We will analyze some of these physical properties.

In the first circular movement of the defender (B's) parry, we will count only the tip of the blade described circle. Let us calculate the velocity (ω) = rad/s. Fencer (B) described a complete circle, which is 6.28 rad/1.1 s, then the angular velocity (ω) is 5.70 rad/s. The author would like to specify that the described velocity of 1.1 s is an approximate number; however, this can be less or even more. The 1.1 s depends on the fencer's skill: how the fencer moves (handles) his weapon. To be more specific about the

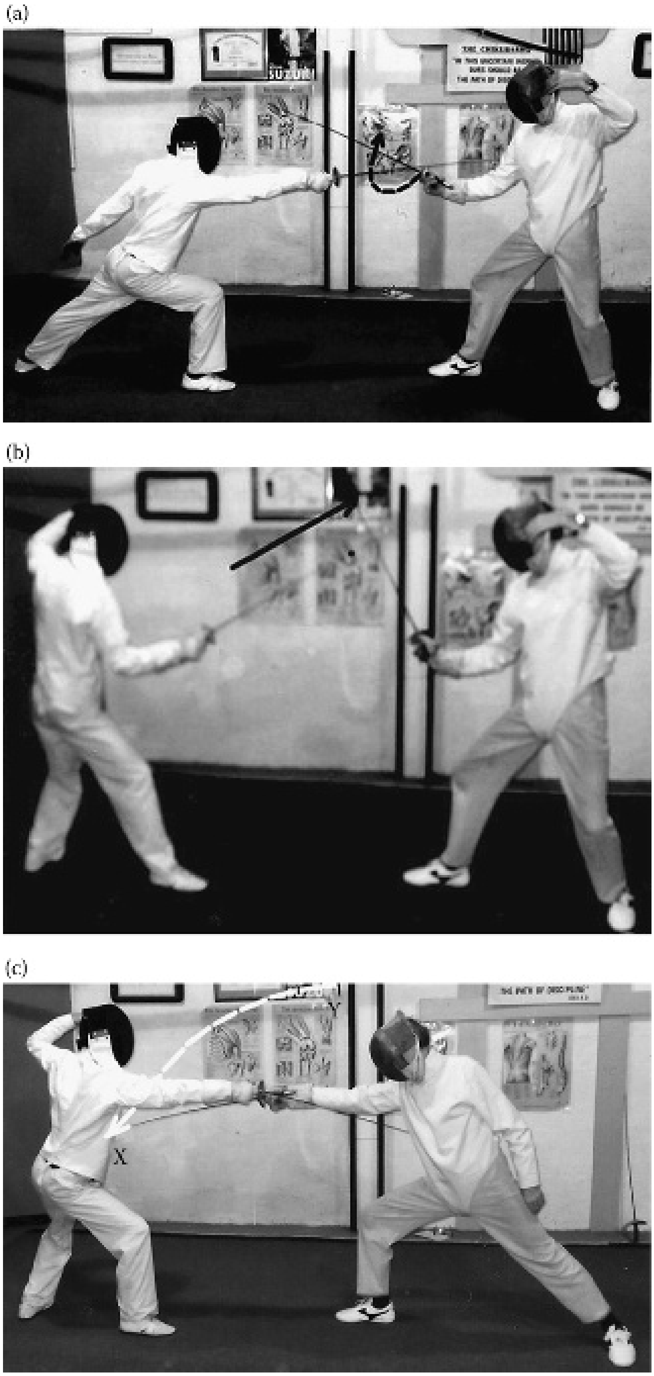


FIGURE 13.6 Engagement, parry, and coupe riposte with lunge.

last statement, here is an additional explanation about the hand rotation by twisting the weapon:

1. When a fencer executes a total circle (disengagement), he can execute the circle with very minimal hand rotation and twisting. In this case, the total length of the blade moves *slowly* because an extra muscular effort is needed for the rotation of the blade depending on the weight of the blade and the wrist *difficult* movement.

2. In some execution, however, the fencer's wrist also describes a circle by moving away his hand a little bit from an initial en guarde position and later returns to the same position; thus, the execution of the circle will be much more easily done. In this case, the muscular effort is put in not only by the hand but also by the forearm muscles and the blade can describe the circle much *easier* and *faster.*

In the last two paragraph, the words *slowly, difficult, easier,* and *faster* have been written in italics and denotes the very essence of any circle made with the weapon of foil. In order to calculate the moment of inertia, you should take into account the first type of circle executed with no or minimal hand movement (change of place). Then $(I) = \text{kg}\cdot\text{m}^2$. For the kilogram, we will use the total weight of the blade, ignoring the guard from our calculation.

The blade weight is ~405–420 g, the blade length is 105 cm; however, the *length of the blade is not prevalent* because we must count the tip of the blade that describes the circle. The author's opinion is that the tip can describe a circle of 0.28–0.32 m diameter (we took the 0.30 m diameter). Then the radius $(r) = 0.15$ m. *The axis for the "r" is an imaginary one.*

Then, $(I) = (0.405\ \text{kg})(0.15\ \text{m})^2 = 0.0091\ \text{kg}\cdot\text{m}^2$. Angular momentum $(L) = I\cdot\omega$. The first equation in parenthesis we know is for the moment of inertia. The second equation in parenthesis is for the angular velocity.

The $(\omega) = \text{rad/s}$. Now, $(L) = [I\ (0.0091\ \text{kg}\cdot\text{m}^2)]\ [\omega\ (5.70\ \text{rad/s})] = 0.051\ \text{kg}\cdot\text{m}^2/\text{s}$. We can calculate the $KE_{\text{ang}} = 1/2\ I\cdot\omega^2$. We let this calculation for the reader to complete.

So far we dealt with the first circular movement. We neglect to deal with the second semicircular movement. We will calculate some physical properties of the third semicircular movement. Recall that this movement is like a whipping action and here the semicircle will be the larger between all three circular movements. By the way, the second and third movements are considered as the technique of coupe. Let us study Figure 13.6c. The

reader can see that the arrow shows an approximate semicircle about 90° from the "Y" to the bottom of the semicircle at the letter "X."

The reader should realize that (B's) weapon handling arm in Figure 13.6c is relatively higher than at the time of parrying. Because the defender (B's) hand is much higher, the semicircle for this reason is difficult to establish. The wrist that is considered as the axis of rotation is not stable at a certain point in space; it is moving away from the initial position. The wrist being higher at the time of hitting is considered a technical matter.

We consider that it does not matter where the wrist will be; it is still the axis of rotation, and the blade length is still the (r) radius of the semicircle. The third semicircular movement of the blade describes 90°. Let us calculate the angular acceleration (α) = rad/s^2. For 90°, the radian = 1.57 rad. Then, $\alpha = 1.57/0.7^2 = 3.20$ rad/s^2. 0.7 s is the $\bar{a}$ velocity.

Calculate $F_{\text{centrip.}} = m \cdot r \cdot \omega^2$. The mass of the blade is 0.405 kg, the distance from the axis of rotation (wrist) to the tip of the blade (r) is 1.05 m, and the angular velocity (ω) 1.57/0.7 = 2.24 rad/s. Then, $F_{\text{centrip.}}$ = (0.405 kg)(1.05 m)(2.24 rad/s)^2 = 2.13 N.

13.1.4.4 Nr.3. Engagement, Parry, and Riposte with Disengagement and Sliding

The attacker on the left side of the figures executes a simple straight thrust against the opponent's chest (Figure 13.7a). The defender executes a quarte parry by moving his strong part of the blade toward his left, reaching at the quarte parry position (Figure 13.7a). The defender from the quarte parry position, which should be held just for a fraction of seconds, directs the top part of his blade (tip) toward his left and down. The arrowhead indicates the direction of the blade (Figure 13.7a). The arrow also indicates the direction that will be outside the attacker's arm.

Figure 13.7b shows another arrowhead that indicates the end of the (tip) blade. Once the tip of the blade is directed downward, the defender must slide his blade on the attacker's blade, holding until the end of the hit. The hit will be targeted on the flank of the attacker (Figure 13.7c).

During the hit, even if the defender did not manage to push the opponent's blade to his right and the opponent's blade touches him at the same time, the defender still has the "right-of-way," which means that his riposte is valid against the attacker's attack. This riposte with disengagement and sliding is very effective.

In Figure 13.7c, the attacker is denoted with (A), the defender is denoted with (D). There are two circles: On the attacker's body the circle labeled

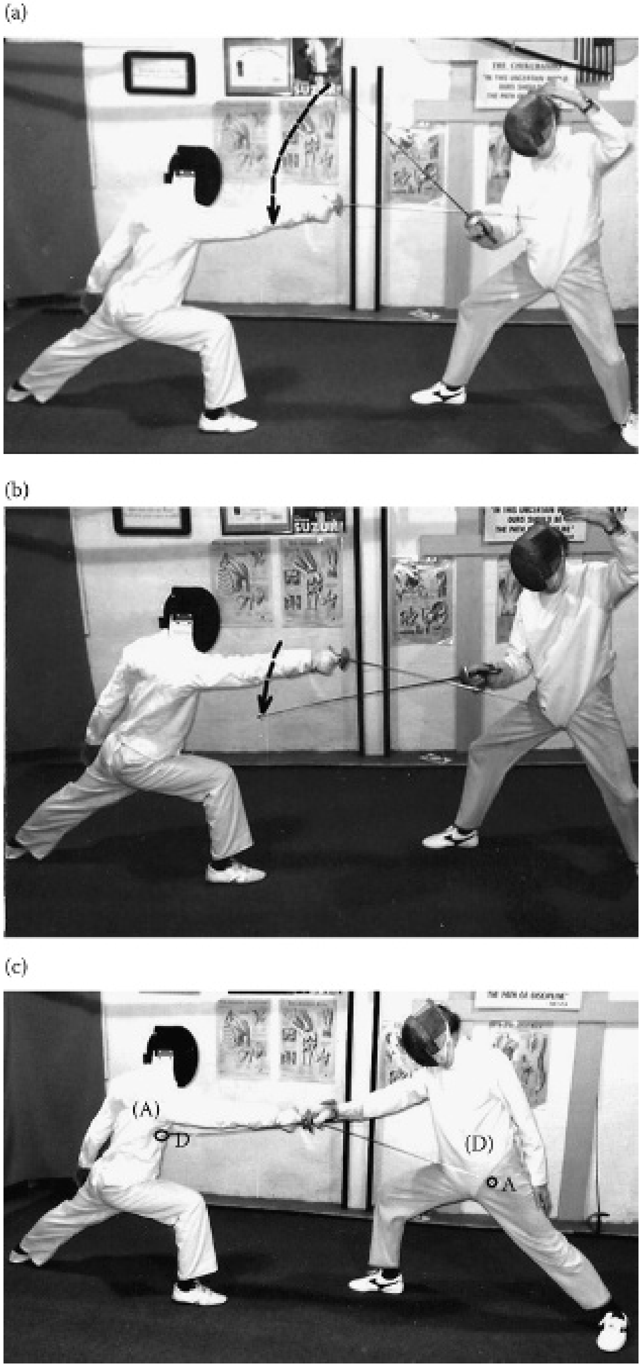


FIGURE 13.7 Engagement, parry, and riposte with disengagement and sliding.

"D" shows the defender's tip of the blade. The circle with "A" represents the tip of the attacker's blade.

In the figure, the defender's guard that holds the attacker at bay can be seen clearly.

13.1.4.4.1 Observation of Physical Properties Looking at the figures of the above techniques, it seems that there are two straight attacks; however, besides the parry and the riposte, there is a sliding with pressure on the attacker's blade. Figure 13.7b shows the defender's correct execution of this technique by holding the attacker's blade at its weak part (end of the blade). By holding the end of the attacker's blade, the defender makes little effort for sliding on the attacker's blade.

Question: Which fencer's blade has more kinetic friction and which fencer's blade puts more pressure on the opponent's blade? When the defender ended his parry and started his pressure with sliding on the attacker's blade, assuming that he exerted more kinetic friction and pressure at the beginning.

The attacker executes a contra friction and pressure with his blade, which theoretically should be equal to the defender's action. However, the attacker, instead of pressing and sliding his blade in the same way on the defender's blade, tries to evade the defender's blade with a disengage movement. In this way, if the defender executes his pressure and sliding riposte correctly, the attacker has a simple role—participating in the pressure and sliding movement of the defender.

To calculate the kinetic friction of the defender's movement, here is the solution. Both fencers have a mass of 70 kg. Each of them can practically exert a similar force with their arm and their weapon. In this case, the kinetic friction (f_K) = (μ_K)(F_N). μ_K represents the coefficient of friction, F_N represents the normal force acting perpendicular on the two blades. The sliding of the defender's blade occurs with an angle of approximately 15° on the attacker's blade, which is kept at an angle of 30°.

We do not count this angle because the angles remain the same between the two blades (the attacker's and the defender's blade) and the defense or the attack occurs in a horizontal direction and not against or with the 30° angle. In this case, the normal force is perpendicular to the blades (point of contact). The steel has a μ_K = 0.80 coefficient when steel slides on steel.

The F_N could be ~40 N (counting one total mass of the arm length with the hand is 3.50 kg) + the total weapon weight is 0.5 kg. Then, (f_K) = (0.58 μ_K) (F_N) = total arm and the complete weapon Newton is 40 N. Then, (0.58 μ_K)

(40 N) = 23.2 N kinetic friction force. During kinetic friction, there is also a pressure. This pressure of course is not static and to find out the pressure of a given area is not important because the area is always changeable. When we talk about kinetic friction, the pressure is always less, then when is about static friction which should be equal with pressure.

During this pressure and sliding of the two blades (let us count only the defender's response of sliding), the defender's blade is involved in work and kinetic energy. When work (W) = $F \cdot s$ (cos θ), then F = 40 N, counting for only one total arm and the weapon. s is the displacement. cos θ is represented by the blade in a sliding angle = cos 15, on the sliding surface, which is in our case represents the attacker's blade held relatively in a static position (Figure 13.7b). The angle is represented by the attacker's blade that is held at an angle of 15°. The total blade length is 0.88 m and we count only a total of 3/4 of the blade at the point from which the sliding began, which is about 0.66 m. The 1.25 s represents an average velocity.

Then the formula for work is (W) = (40 N)(0.66 m)(cos 0.965) = 25.47 J. $KE_{\text{linear}} = 1/2\ m \cdot v^2$. Then, 1/2 (4 kg, total arm and weapon)(1.25 s)^2 = 3.12 J of kinetic energy is consumed.

13.1.4.5 Nr.4. Engagement, Quarte Beat Attack, Prime Parry, and Riposte

The attacker is on the left side of the figures. He executes a "quarte beat attack" (Figure 13.8a). The beat from the attacker is executed toward his quarte parry position and uses his blade's middle part against the defender's middle part.

The defender executes a prime parry by dropping his blade and moving toward his left, as shown in Figure 13.8b. Also, in Figure 13.8b, there is a little circle that shows the initial position of the defender's fist (see the fist lower in Figure 13.8a). These two positions show that as the fist rises (see the semicircular line in Figure 13.8b), the tip of his blade descends. The defender from this position simply extends his arm with his blade and scores on the attacker (Figure 13.8c).

The arrow in Figure 13.8c shows the direction and the target of the hit. The short black arrow shows the final position/touch also the direction from where the defender's tip started.

13.1.4.5.1 Observation of Physical Properties Let us analyze the attacker's motion first. During the attacker's quarte beat on the defender's blade, there are force and impulse that can be observed.

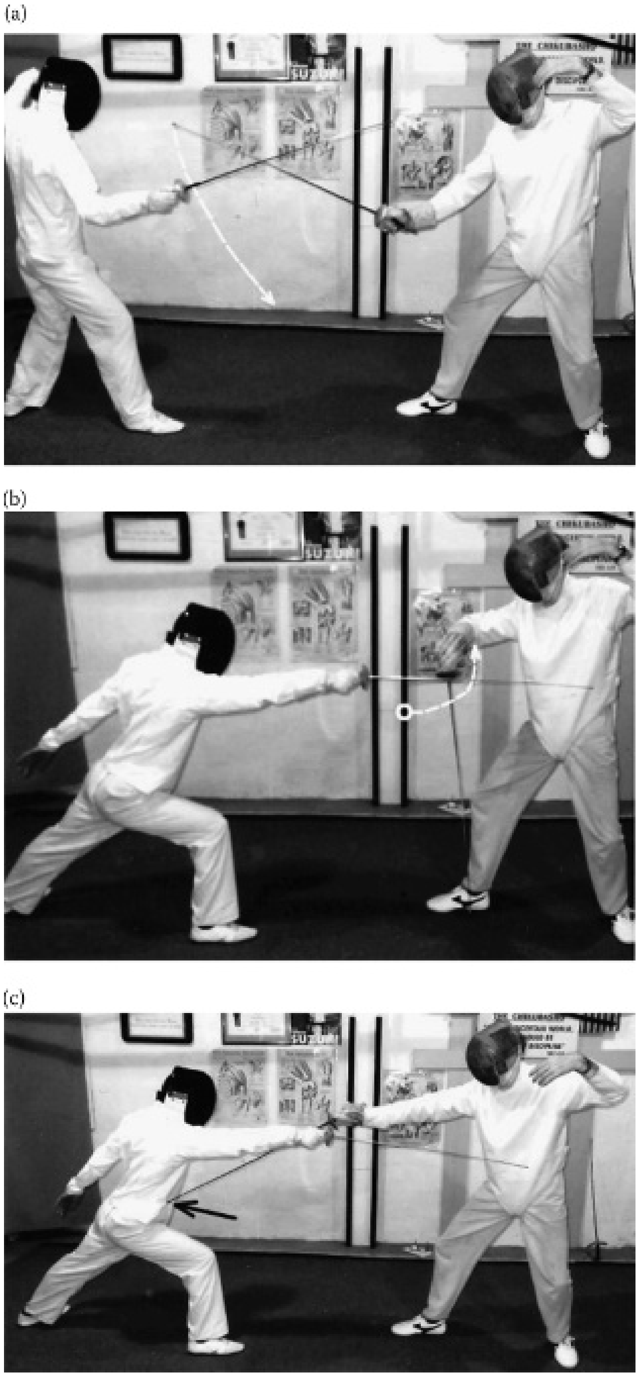


FIGURE 13.8 Engagement, quarte beat attack, prime parry, and riposte.

For the execution of the beat, the force is minuscule, but it is extremely important. The impulse is minuscule too (the time is extremely short). The momentum is important where the velocity should prevail versus the mass.

At the time of starting the momentum $(p) = m \cdot v$, the mass in our case and the strength of the forearm and wrist is extremely important because the execution of the beat requires a good energetic forceful hit on the blade and short but forceful twisting motion. If the mass and the strength of twisting of the forearm and wrist are executed fast and correctly, then the attack can be successful and the defender will be late to stop the attack with a prime parry.

However, if the beat attack is weak, or the defender is skillful, he can simply drop his blade and use the prime position for blocking the attack.

13.1.4.6 Particularities of Epee Fencing

The epee (literally meaning "sword" in French) is the heaviest form of all three weapons. With this weapon, you can attack any part of the human body, but only with a thrusting motion. It is quite unpleasant when your opponent thrusts against your mask that covers your head. Also, it is quite painful when you get a thrust to your shoe, particularly at the toe level or on your knee. The guard is quite large to protect your wrist and forearm area.

The blade is thicker and the guard is much larger than the foil weapon. We are not entering into a detailed explanation about the rules of the epee contest. We could briefly translate the meaning of the entire fencing bout, which literally means "anything goes." Who hit first is signalized; a double touch is also registered if both fencers hit each other at the same time or a small time difference within 1/25th of second time rate.

Epee fencing is a time-consuming sport. This is because the bout is for five touches. When one of the fencers leads 4–3, then when a double touch occurs, the fencer who attacks or parries hazardously will lose 5–4. For this reason, many fencers after taking the lead will stay in defense and go for double touch to assure victory. Among the other types of tactics, the attacker tries to hit the arm or the shoes of the opponent because those body parts are closer to him and the risk is reduced.

We will show two typical attacks and the possible outcome of these attacks or the possible outcomes of the defense. We shall explain the tactical solutions of these attacks too.

13.1.4.7 Nr.1. Attack Direct on the Arm—Nr.2. Attack Direct on the Knee

In Figures 13.9 and 13.10, the attacker is on the right side. In Figure 13.9, the attacker attacks the defender's weapon-holding arm under the epee's guard with a direct hit. Two important points need to be explained:

1. If the attacker decides to go for the hit of the arm, he never can *thrust straight* like in foil. In this case, when he tries to hit the defender's arm, he must drop his entire arm with the blade a little bit horizontally; then he can thrust forward by lifting up a little bit of the tip of his blade.

   It is impossible technically to hit a forearm straight, which is held pretty much horizontally to the ground and is also protected by a

FIGURE 13.9 Direct attack on arm.

FIGURE 13.10 Direct attack on knee.

large guard, because in a straight hit like in foil, the touch could slide from the defender's forearm. If the attack is directed against the upper arm, the thrust is the same as in foil fencing.

2. In Figure 13.9, the defender holds his fist higher than the safety level. Basically, this position is for tactical reason (we will not explain this at this time). In case of a direct attack as we described earlier, the defender basically just drops his fist and is protected by his large guard. From here he has numerous possibilities to counter the attack.

Examining in Figure 13.10 the possibility of the attack on the knee or even on the shoe of the defender, we can describe the following actions of the defender:

1. The simplest defense of the defender is to pull back his right leg and at the same time thrust the attacker's mask. This movement must be done at the same time; otherwise, the attacker will do something else if he loses the knee hit. Figure 13.10 shows that the attacker held his fist pretty low; the reason for this to be ready for an eventual defensive action. He should not hold his fist lower in this attack as shown in the figure.
2. The defender, instead of hitting the attacker's mask, can use a parry of octave or second excluding the attacker's blade toward his right and can immediately score with a straight hit against the chest of the attacker. Of course the defender has many other possibilities to counter his attacker.

In Figure 13.9, the black circle above the attacker's arm indicates the previous position of the attacker's arm. The arrow indicates the direction of dropping the arm. In Figure 13.10, the white arrow indicates the defender's right leg movement. The backward movement should be a little hopping motion with a counterthrust on the mask of the attacker.

13.1.5 Attack and Defensive Techniques in Saber: Biomechanical Characteristics

Saber primarily is a cutting weapon. However, it is also used to thrust an opponent. Saber is considered the master weapon. In saber fencing, attacks are preferred instead of parries. Classical saber fencing where the defender could hit an attacker's arm three times before being hit by the attacker is gone long ago. Now, athletic fencing rules the game.

13.1.5.1 Particularities of Saber Fencing

In saber, just like in foil fencing, the most important physical property is speed with displacement, and then comes energy, momentum, and so on, all these physical characteristics guided by skill and endurance. Defending against a saber attack theoretically is easier because a large movement of a cut with a saber is more visible than a straight thrust with a foil. For this reason, in saber attack, there are more feints, second intention attacks, and other maneuvers that help the attacker to score a point.

Highly skilled saber fencers often use a counteroffensive movement, which is the stop cut on the arm. This stop cut executed on any side of the forearm. For this cut the defender must be extremely attentive to choose the correct timing for the cut to be executed. In saber fencing, the technique of beat or press and slide on the opponent's blade is executed similarly to foil fencing, however, with extra care for the following reasons:

1. At the time of a beat against the opponent's blade in foil fencing, there is an immediate attack or disengagement will occur. For this reason, a stop thrust against the attacker will have no "right-of-way" will be late.
2. In saber beat attack on the opponent's blade, there is an opportunity for the opponent to use a stop cut on the attacking arm of the opponent. How do these two stop thrust and stop cut differ from each other from a biomechanical point of view?

In foil after the beat attack, the attacking arm will be straight oriented forward with the attacking blade. In this case, the threat is very close to getting hit. In saber after the beat attack, the weapon-holding arm is extended; however, the blade is not, which will come later to hit the defender. In this case, because the arm is closer and the blade is farther from the defender, he can use a stop hit on the attacker's arm.

Question: Why is the arm extended and not the blade (it is held somewhat to 45–65° to the vertical line from the ground; see Figure 13.4b)? This is because if the blade is extended, for example, for a head cut, then the arm will be elevated to a higher level to reach the head. In this case, an elevated arm gives an opportunity to the defender to execute a stop hit under the guard of the attacker's arm. For this reason, the saber fencer must be close all the time to the defender at the time of executing a head cut.

When a saber fencer executes a beat on the opponent's blade or more importantly executes a sliding pressure, his right arm (in case of right-handed fencer) is always exposed somehow to the defending opponent. Pressure with sliding on the opponent's blade is not executed often since the Olympic Games of 1960. Fencing in the late 1950s and the early 1960s was highly technical. From the beginning of the 1960s, fencing became highly athletic. Almost everything became simplistic with the accent only on speed.

13.1.5.2 Nr.1. Quarte Beat and Head Cut

The attacker is on the right side of the figures, noted as (A), and executes a quarte beat (Figure 13.11a). The execution is exactly on the middle of the opponent's blade with the middle of the attacker's blade. The attacker's right arm is a little bit exposed to the opponent. Because the defender's arm is extended, he cannot use a correct stop cut on the attacker's right arm. The beat must be executed with a sharp and twisted movement similarly to the foil beat. (A) executes the head cut with a lunge.

13.1.5.2.1 Observation of Physical Properties Momentum is observable just like the beat in foil fencing. In saber beat and cut, we have two kinds of touches: one is on the blade of the opponent and the other is on the mask of the opponent. These two cuts or beats have different force manifestations:

1. The beat on the blade is heavier than on the foil blade, where the two middle parts meet.
2. The cut on the mask is much lighter, executed with the lighter part of the attacking blade (end of the blade). Each of them has the momentum and the impulse. For both technical executions, the time is relatively very short and probably similar too. In both beat/cut, you must use your force to get a correct acceleration. The acceleration will be high because the mass of the blade is very low (think about the weight of the blade).

In each touch execution, the speed is the most important. After the execution of the beat on the blade, there will be an impulse and acceleration. The rebound force from the impulse gives the blade acceleration for the cut on the head. Let us calculate further on the acceleration time.

When the blade weight is about 0.5 kg, then the direct hitting force (N) = (0.5 kg)(9.8 m/s^2) = 4.9 N. In this hitting force, we did not count the

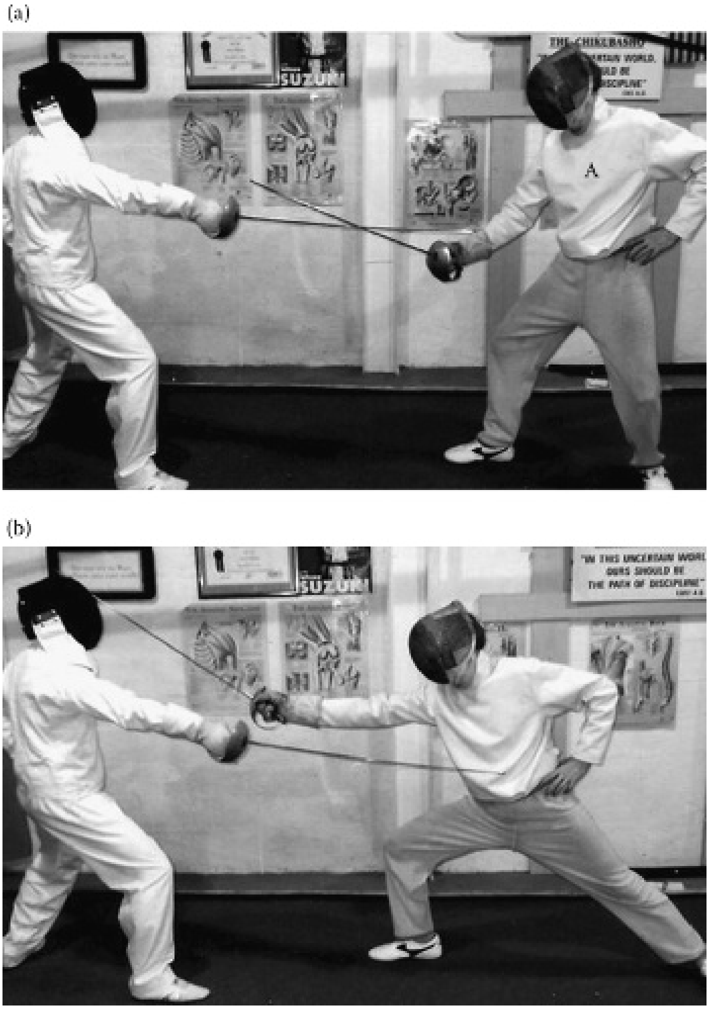


FIGURE 13.11 Quarte beat and head cut.

impact or impulse because the hitting is extremely light and extremely short in time. $\bar{a}$ = m/s^2. The distance from the saber guard position of (A) to beat on the opponent's blade position is ~0.40 m, which depends on the opponent's weapon-holding arm. The average acceleration is 0.4 m/s^2. Then, $\bar{a} =$ 0.40 m/s^2. The contact time on the blade is 0.1 s.

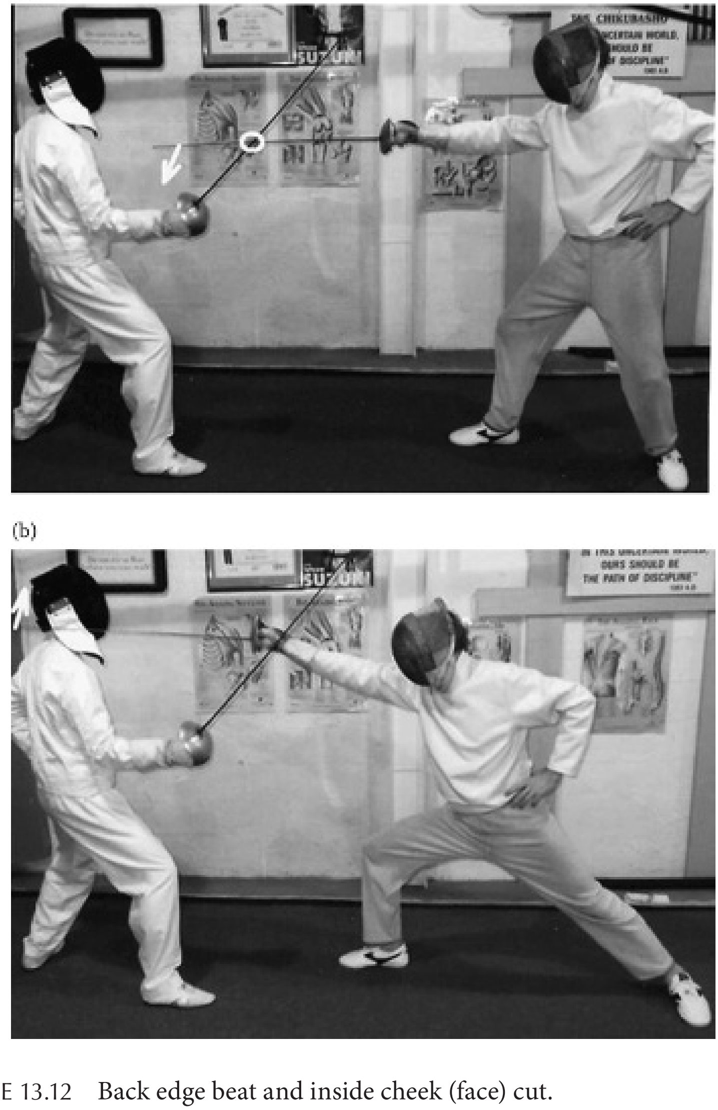
Let us calculate the momentum, impulse, and the impact force. The momentum for the beat on the blade (p) = $m \cdot v$ or (4 kg)(0.1 s) = 0.4 N·s (4 kg represents the total arm plus the blade weight). The impulse (J) will be (p) = $\Delta p = F\Delta t = (v_f - v_i)$ = (J) = Δp = (4 kg) [(−0.2 m/s of v_f)−(−0.4 m/s

of v_i)] = −2.4 N · s. $F = J/t$; then, (−2.4)/(−0.1 s) = −2.5 N. Continuing to execute the head cut, the acceleration will be more than $\bar{a} = 0.4\ \text{m/s}^2$, which has been described above.

13.1.5.3 Nr.2. Back Edge Beat and Inside Cheek (Face) Cut

This attack can be executed very easily. This attack is also extremely efficient. The attacker (A) is on the right side of the figures. Figure 13.12a

(a)



(b)

FIGURE 13.12 Back edge beat and inside cheek (face) cut.

shows how the beat is executed. In this figure, where the two blades meet, there is a circle. At the end of (A's) blade, the white arrow shows the direction of the beat, which is directed toward the attacker's left side.

In this technique for the beat, (A) should use a very light force, and then extend his blade between the defender's blade and his cheek. On arriving close to the cheek, (A) will cut gently the defender's cheek. Behind the defender's mask the white arrow shows the direction of the cut, which is toward the right of the attacker (Figure 13.12b).

When the attacker is close within a simple lunge distance, the defender, most of the time (as a reflex motion for parry), will push the attacker's blade toward his cheek. To defend against this attack, there are two possibilities: The first one is the "bobbing down" (Passato Sotto in Italian). The next one is when the attacker beats the defender's blade, try to pull back your arm and step back. The third one will not be described here because the parry is very old fashioned and is not used in present fencing. We will not describe any physical properties related to this technique.

13.1.5.4 Nr.3. Attack Direct Head Cut, Flying Parry, and Riposte

The defender who executes the flying parry is on the right side. The attacker (A) on the left side attacks with a cut directed to the head of the defender; the attack is executed with a lunge (Figure 13.13a). Also, in Figure 13.13a, the arrow shows the defender's blade route, which slides (for control reason) under the attacker's blade, and then will goes around the attacker's tip of the blade.

In Figure 13.13b, the defender's blade is already outside the attacker's blade and goes straight for a chest cut, which is shown by the white arrow. The flying riposte is always directed against the attacker's chest, and seldom against the attacker's belly or the head.

In Figure 13.13c, the defender's arm is extended and is raised up a little bit. There is no danger for the defender to get a stop cut because his arm is already in motion, and the timing for stop cut will be late. In Figure 13.13d, the defender executes the flying riposte on the chest of the attacker, and the arrow shows the route of the blade and its movement back toward the defender. The defender executes the riposte with a lunge.

In Figure 13.13e, the defender's blade has already executed the chest cut and it is outside the attacker's body and from the attacker's knee. Then the blade will return with the defender in an en guarde position (Figure 13.13f—the defender is without mask in this figure).

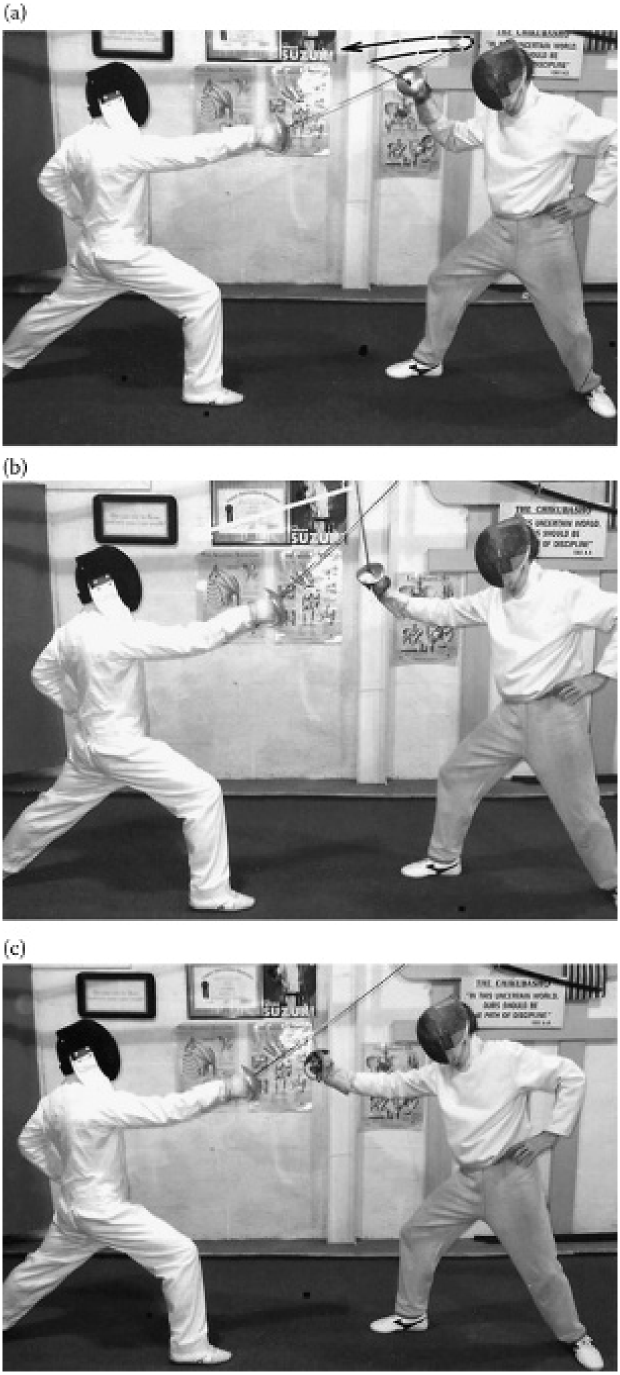


FIGURE 13.13 Attack direct head cut, flying parry, and riposte.

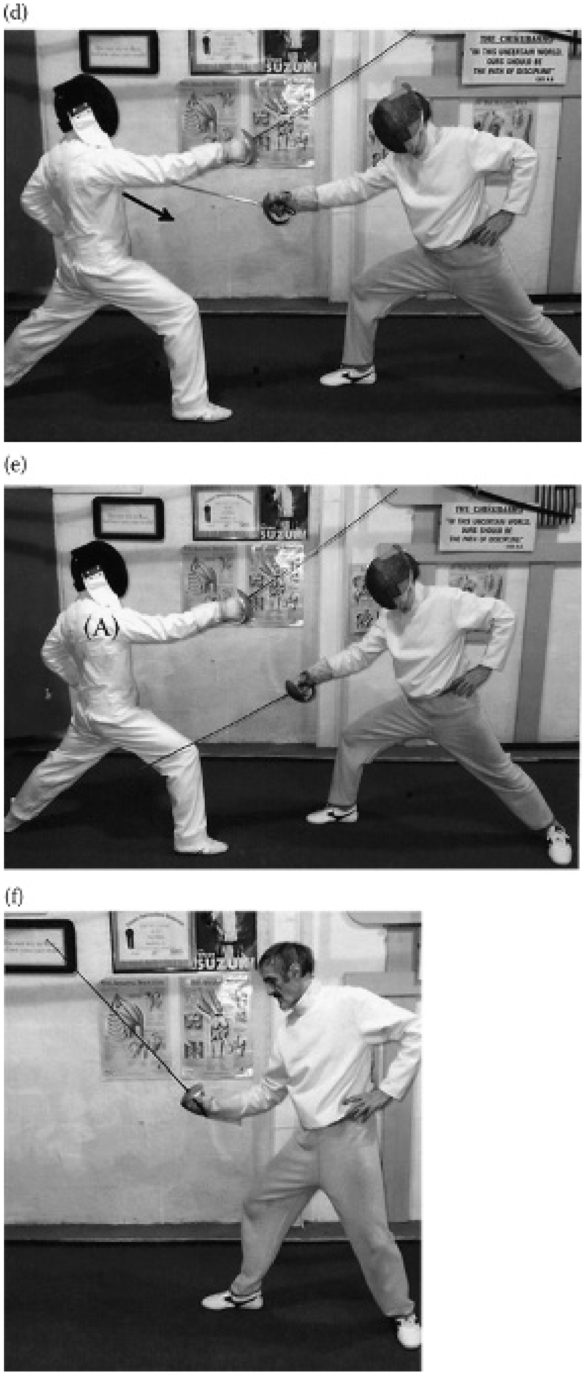


FIGURE 13.13 (Continued.)

13.1.5.4.1 Observation of Physical Properties This "flying riposte" technique is probably the fastest from any kind of riposte executed by a saber fencer. This technique has advantages and disadvantages.

Advantages:

1. It is the fastest cut in saber fencing.
2. It is relatively easy to execute.
3. From a parried position (Figure 13.13b), the defender, instead of continuing the flying parry, can change his mind and can execute a stop cut on the attacker's forearm outside.

Disadvantage:

1. See Figure 13.13b again. The attacker can push backward the defender's blade by sliding on his blade toward his weapon's guard. By this action the attacker can change his mind and can execute a "remise."

Analyzing the attacker's physical properties, we have the momentum a very little impulse because the hit is not direct, where the impulse could be obvious, and certainly the velocity of his attack. Analyzing the defender's physical properties, we have momentum, impulse, kinetic energy, acceleration, and so on. We let the reader to challenge him.

13.1.5.5 Nr.4. Quarte Beat–Arm Cut

This technique is very similar to Nr.1 technique (Figure 13.11). The attacker noted (A) is on the right side of the figures. The cut on the arm is executed on the inside part of the forearm. This attack, however, should not be considered as a stop cut on the arm. This technique is executed only when the opponent extends his arm and gets ready to beat the attacker's blade; then the opportunity has been presented for the attacker to execute the quarte beat–arm cut.

In Figure 13.14a, (A) beats the defender's blade in the middle (see the circle). The arrow shows the direction of the beat on the blade and further cut on the arm. In Figure 13.14b, the larger circle shows the actual spot where the cut is supposed to be executed. The figure also shows the end of the blade with a very small black dot on the defender's arm.

Seeing this, the reader would believe that the technical execution is not so good. The reason for where the dots can be seen is because at the time of the beat on the blade, the defender moved his arm forward. The attack is executed with a lunge. The beat and the arm cut can also be

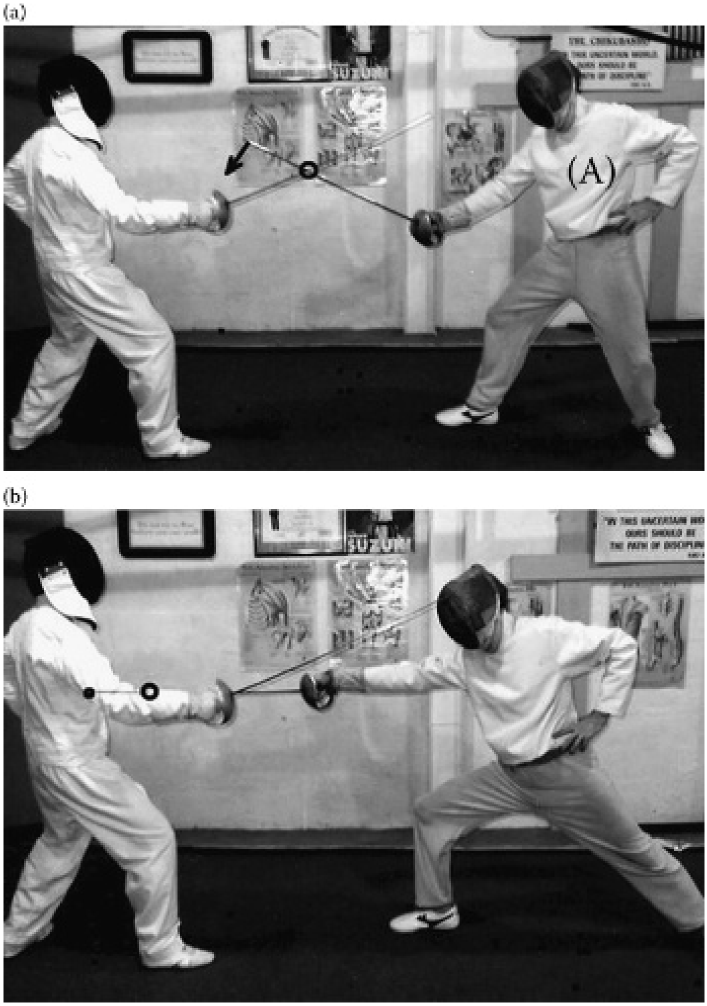


FIGURE 13.14 Quarte beat–arm cut.

executed without lunge. This depends on the timing and the distance between both fencers. This technique is relatively easy to learn and easy to be executed.

13.1.5.5.1 Observation of Physical Properties Where there are two objects to collide, we have momentum, impulse, and impact force. In saber, however, the straight cut, such as beat and/or cut straightforward from the tierce position, there is always an observable short semicircular movement.

Recall the saber fencer when cut, for example, the mask of the opponent; first, he extends his arm by holding his weapon blade approximately 30–45° from the straight vertical position, then when the arm becomes close to the mask, he executes the cut with a semicircular movement. Keep in mind that the axis of rotation is the attacker's weapon-holding wrist. Like in karate, every kick that intends to go forward by a straight linear motion, the kick itself is always executed angularly. In saber fencing, every cut is also executed angularly.

13.1.5.6 Nr.5. Head Feint–Flank Cut

This is a very basic attack. Every saber fencer should know it. Recall that the feint must be executed slowly. The reason of showing the feint slowly is to create an opportunity for the opponent to react. In modern fencing, the feint apparently is executed extremely fast. How should this contradiction be understood? Here are some reasons:

1. If the feint is executed slowly (against the timing of the attack), then there is a chance that the opponent could execute a stopping attack, such as thrust or arm cut.
2. If the feint is executed very fast (against the timing of the attack), then the opponent will not react and the attack is wasted, most probably will be finalized where the opponent's weapon is.

So, how should a feint be executed correctly?

1. If the attacker has a beginner opponent, then the motion of the feint starts slowly and observing the opponent's reaction under a millisecond time, the motion of the feint should continue faster (with an accelerated motion) until the defender's final reaction, when the attack can be finalized.
2. If the attacker has a highly skillful opponent, the feint should start with the "game of the weapons" (beat, press, slide, etc., on the opponent's blade) and observing the opponent's reaction, finally the feint can be executed fast.

Figure 13.15a shows the final movement of the feint. Figure 13.15b shows the attack on the flank of the opponent. Some of the physical properties are: momentum, speed of the feint, and speed of the final attack

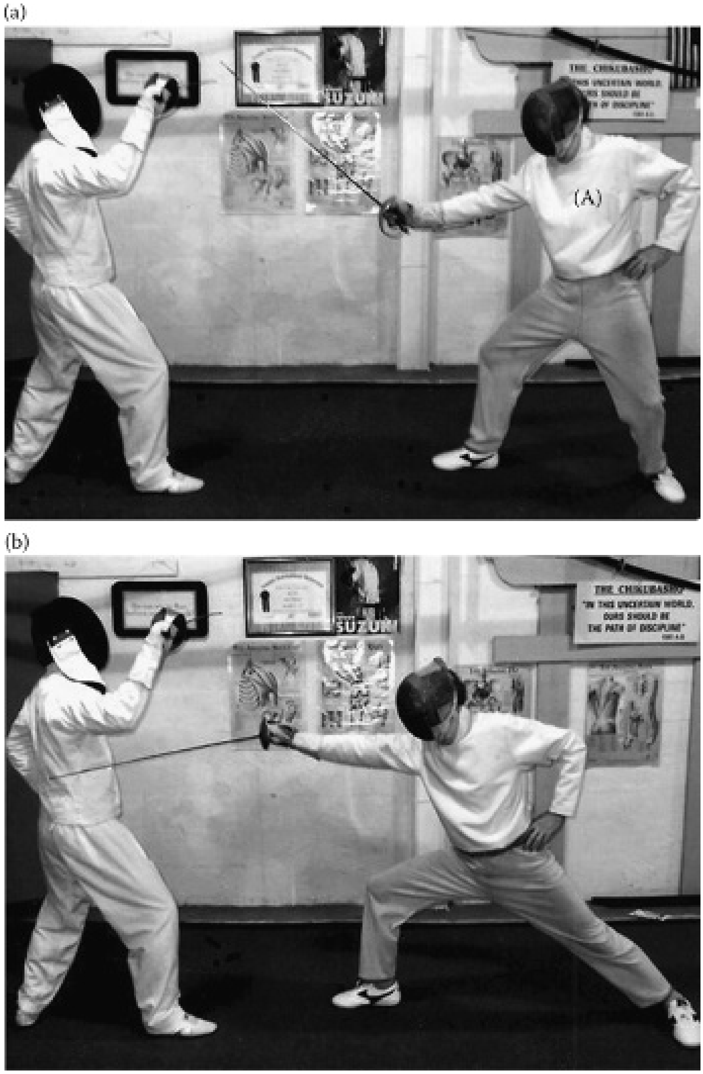


FIGURE 13.15 Head feint–flank cut.

with change in momentum and the unstable balance of the attacker position during the lunge. Kinetic energy as always would be observed.

13.1.5.7 Nr.6. Direct Attack with Coupe Cut (Touch)

This attack is very seldom used in saber fencing, contrary to foil fencing, where is used many times. The execution is very similar to the foil coupe

execution. The hit will be done only with the top of the blade (the last part of the blade, the weakest part). The problem with the saber coupe attack execution is that the executor arm must move outside (just like in foil fencing) in order to score the hit.

During this time, the hitting arm is exposed to the stopping attack. A disadvantage is that it is more easier to be parried than the foil attack. In foil attack, the attacker concentrates only on the fishing movement; meanwhile, when executing the coupe attack in saber fencing, the attacker must concentrate on the last part of the blade and not only on the tip of the blade.

Attacker (A) is on the right side of both figures. The long arrow shows the direction and the finalization of the attacking blade on the chest of the defender. The small semicircular arrow at the defender's arm shows the direction of the defender, who is already moving toward his quarte parry position (Figure 13.16a). Figure 13.16b shows the final position of the attacker's blade and the arrow shows his forearm direction, which moves to the right of the attacker. The attack is executed with the back edge of the blade.

13.1.5.7.1 Observation of Physical Properties This attack does not intend to cut the opponent's chest directly. The attacker's forearm and especially his wrist have the major physical role in this coupe attack. Figure 13.16a shows the tierce basic position of the saber fencer. From this position, the attack cannot take place in the usual way, which is to extend the arm parallel with the ground, and then continue to extend the arm with the blade inclining forward until the position when the defender can be hit.

In the coupe technique, the attacker's arm will be extended laterally almost completely, with an angle of 30° observed from the straightforward line direction. From here, the fist of the attacker will flip and turn over (Figure 13.16b) with a very fast motion.

At this time, the attacker's blade should be thrown like the fisherman's rod during fishing time. The result will be a touch on the opponent's chest and not on the opponent's belly. Hitting the opponent's belly is dangerous because the defender's guard could close the gap against the attacker's blade.

With this flip and turn over motion, the attacker gains a correct position for the attack and also gains some momentum for the attack. The

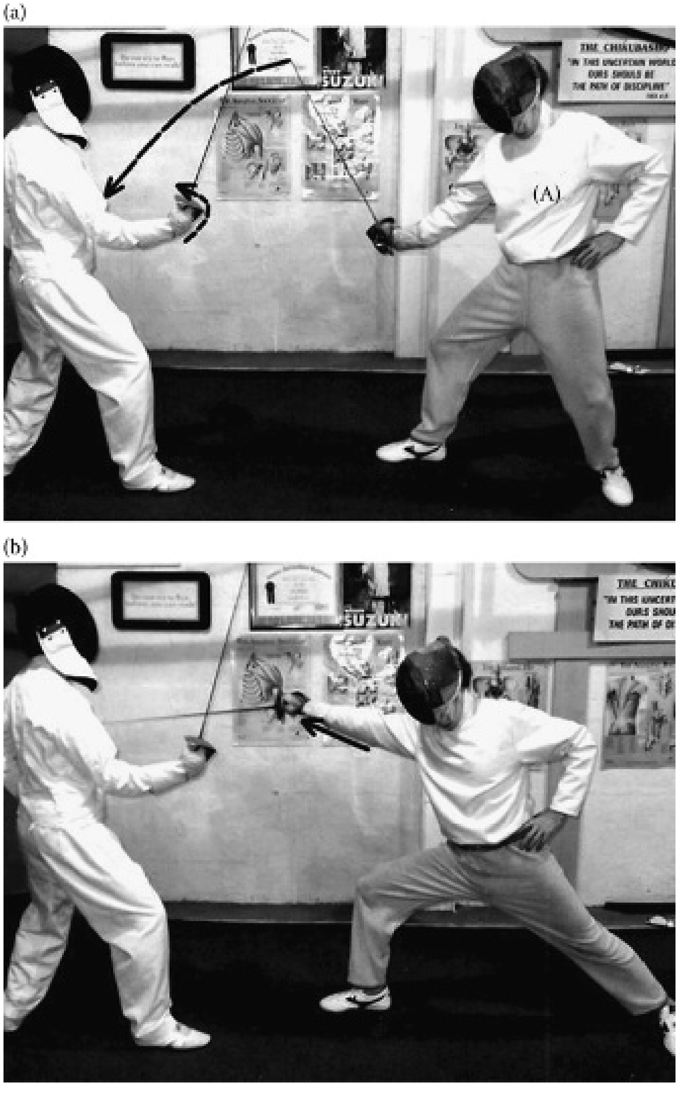


FIGURE 13.16 Direct attack with coupe cut (touch).

attacker could remain in a very vulnerable position if he does not hit the target. From this position, the defense is extremely easy.

There is more technique to describe; however, we will stop right here. A good fencing book will help to better understand the techniques described above. Above all, fencing is a very complex sport. Those with some basic practice background of at least 1–2 years have a better chance to understand the techniques described herein.

13.2 BIOMECHANICS OF THE KNIFE (*TANTO*) DEFENSE

This chapter will be similar to Chapter 12. The physical properties that are described here will deal mostly with leverage and for some techniques they can be used to calculate the power, momentum (p and L), and radial force.

The author will describe four defenses against knife attack using the techniques from the Sendo-Ryu Karate-do knife defense requirement for black belt students. Before describing the first technique, the reader must know some important points of defensive techniques from psychological and biomechanical points of view:

1. Defending against an aggressor who attacks with a knife is a life-threatening situation; that is why the best defense is to retreat.

2. When an aggressor attacks using his right hand, the defender should be positioned at the time of active defense at the right side of the aggressor. The difference between active and passive defenses are: (a) Passive defense basically is any movement of positioning your body safely to be able to execute the active defense. (b) Active defense is the movement when the defender grabs the attacker's limb (the attacking arm or the nonattacking limb [arm or leg]).

3. The defender should hold a convenient distance for him to enter into the attacker's attack.

4. The defender should not concentrate only on the attacker's knife-holding arm but also to see the opportunity of stopping the opponent with a kick or with any other object, which can be thrown at the attacker's face to disorient him for a moment.

13.2.1 Nr.1. Attack Direct into the Defender's Abdomen and Its Defense

The attacker is on the left side of the figures. Figure 13.17a shows the position ready for attack. The attacker steps forward with his right leg and swings his arm and tries to stab the defender in his stomach. At the same time, the defender steps back with his left leg and by sliding down both his arms tries to grab the attacker's stubbing arm wrist (Figure 13.17b).

In Figure 13.17b, the tiny arrow on the right arm of the attacker indicates the defender's both arms sliding down motion. This slide down will create a permanent control over the attacker's arm. It is absolutely contraindicate not to hit or try to grab right away the attacker's arm.

By sliding the arms down, the defender has a better choice to change his arm's position in case the attacker tries to pull back his arm from the attack. To better understand this sliding motion, the defender should go with the attacking arm motion in order to finally grab the attacker's stubbing arm at his wrist.

In Figure 13.17c, the black arrow indicates the defender's thumb sliding at the proximity of the second, third, and/or fourth metacarpal heads. At the same time, his left palm four fingers will slide under the attacker's palm (exactly under the knife handle) and will then turn the attacker's palm in such a way to be oriented, first to be in a supine position, then to be bent back toward the attacker's forearm (Figure 13.17d).

The defender can now bend/push the attacker's knife-holding hand with both his hands. The defender continues to hold with both hands the attacker's back of the palm and lifting up against the force of gravity (Figure 13.17e). The defender now will pull the attacker's arm and at the same time kick his groin, stomach, or knee (Figure 13.17f).

(a) (b) (c) (d)

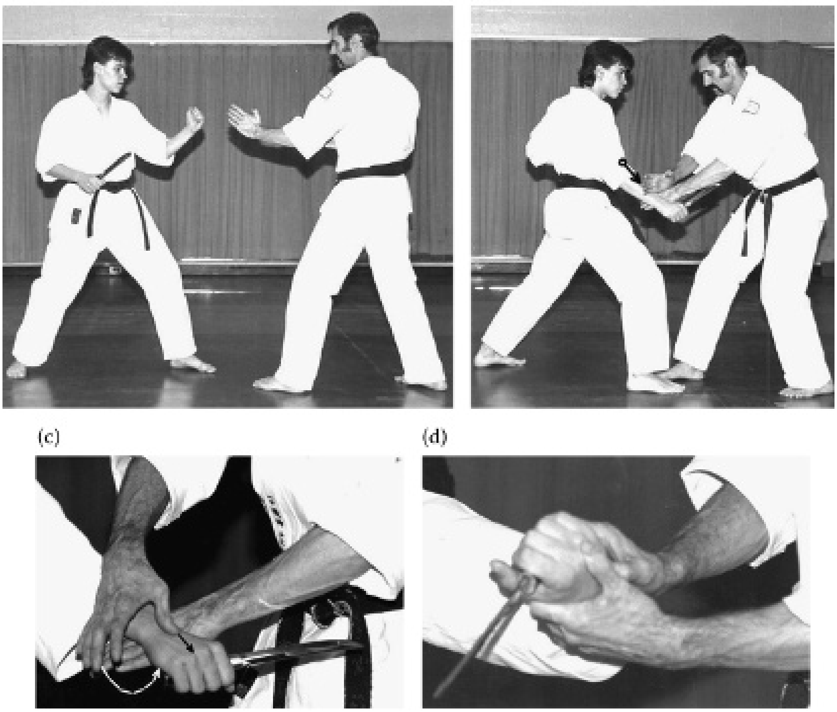


FIGURE 13.17 Attack direct into the defender's abdomen and its defense.

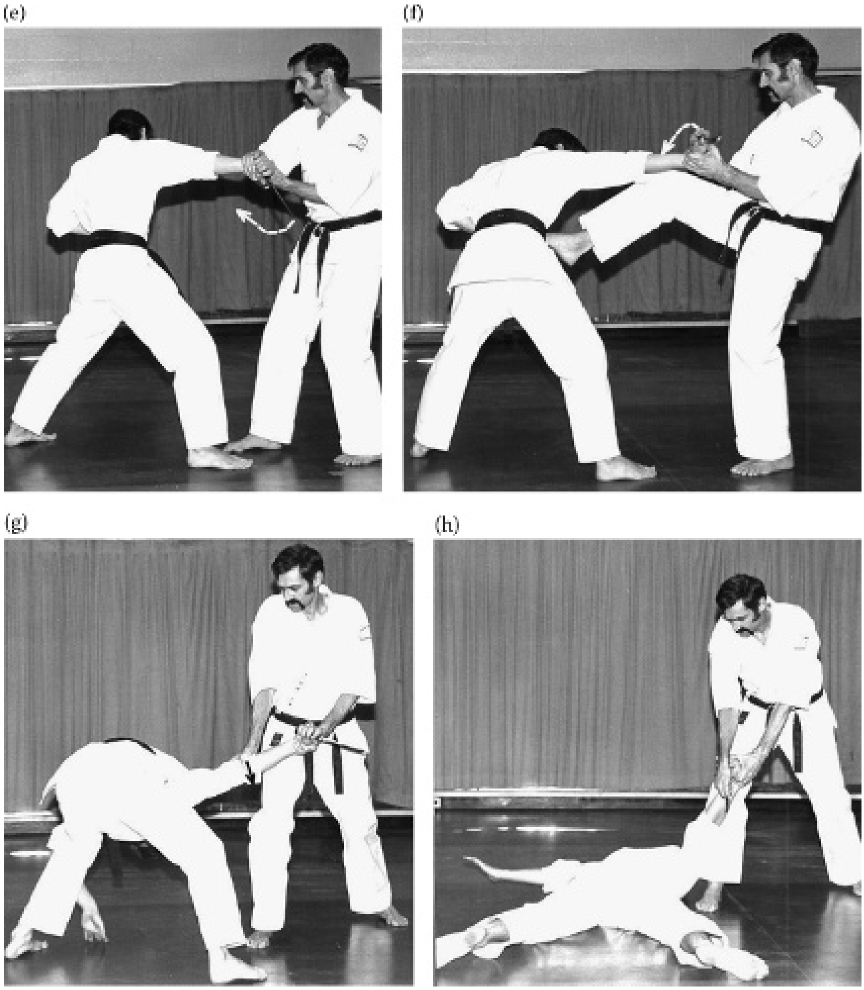


FIGURE 13.17 (Continued.)

The defender continues his defense by pushing down the attacker's elbow with his right palm and lifts up the attacker's knife-holding arm a little bit with his left hand (see the tiny arrow on the attacker's elbow; Figure 13.17g). With this action, by pushing down with the right palm and by lifting up with the left hand, the defender can hold the attacker's arm in an extended position and can inflict serious pain to the attacker. Figure 13.17h shows that the defender managed to take away the knife and he can cut (if he want) the attacker's arm.

13.2.2 Observation of Physical Properties

The attacker has a very good momentum that will be conserved by the defender only because he did not oppose with force during his defense. Recall the conservation of momentum derived from Newton's first law of motion, which states that a system of bodies will continue to move in a straight line unless acted upon an external force. In our case, the external force could be the defender arms; however, the defending arms did not act as an opposed force.

Normally the attacker has a good force, power, velocity, energy, and so on until the time when the defender managed to grab and twist the attacker's arm. From this point, the defender will dominate with different physical properties over the attacker.

The twisting arm maneuver by the defender will require strength and at this time, the momentum is lost for the attacker. The defender uses the attacker's arm as a lever and imposing a force at the end of the lever, which is his hand. See Figure 13.17f and 13.17g.

Earlier it was mentioned that at the time when the defender managed to grab and twist the attacker's arm, he had many different physical properties to count on. It is very difficult to establish a correct physical property because the twisting motion becomes a partially rotational motion (when the attacker's arm is lifted up) and the attacker's arm is pulled to be straight for the kick.

All these movements happened extremely fast with a very short time of action. So, for this reason, the author considers not to describe any physical properties.

13.2.3 Nr.2. Attack the Abdomen, Then the Neck or Face and Its Defense

The attacker is on the right side of the figures. This attack is similar to the previous one (Figure 13.18a). The difference is the following: In the previous attack, the defender slided down both his arms on the opponent's arm when he blocked the stabbing knife. In this technique, the defender blocks energetically at once the attacker's arm with both his hands (Figure 13.18a).

The attacker seizes this blocking movement and will change the stabbing movement from the stomach to the side of the neck or to the face of the defender (Figure 13.18b).

Figure 13.18c shows the defense against the neck stabbing position. The defender basically follows the attacker's forearm, sliding on it with his

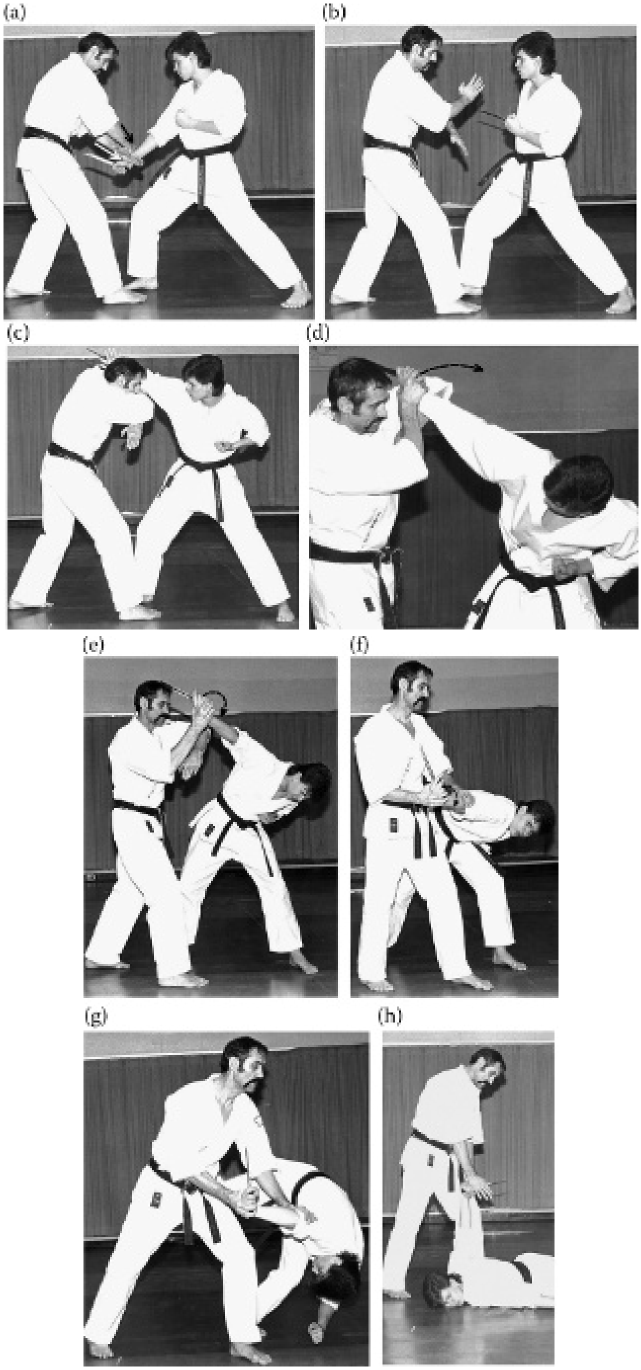


FIGURE 13.18

right palm and at the same time enforces his defense by moving his left forearm under the attacker's forearm by lifting it up (Figure 13.18c).

Figure 13.18d shows the defender's left forearm still supporting the attacker's forearm. The defender grabs with his right palm the attacker's wrist and twists it in the clockwise direction as shown with the arrow in Figure 13.18d and 13.18e.

At this point the attacker could roll forward and escape. The attacker should bend his right elbow during his rolling forward to ease his escape. The defender will guide the attacker and when he reaches the ground (he will be on his back), the defender must guide the attacker to be on a prone position (Figure 13.18h).

In Figure 13.18e, the defender twists the attacker's hand in a clock wise direction. In Figure 13.8f, the defender steps forward with his left leg, pushing down the attacker's arm with his left palm or the edge of the palm on the attacker's elbow.

In Figure 13.18g, there are two options for the attacker to escape: first, the defender normally tries to push down the attacker and hold him down using the Aikido position of IKKYO. This position can be executed relatively easy; however, if the defender somehow loses the correct technical execution, then the attacker could roll forward.

Note: Do not forget that when the defender successfully grabs the knife from the attacker, he becomes the attacker, so the roles will be changed.

Figure 13.18h clearly shows the defender's left arm pulling up the attacker's arm and the defender's right arm pressing down on the attacker's back of the palm. This action can be considered as a "force couple" because both hands basically do or intend to do a circular movement where those two forces act on.

13.2.4 Observation of Physical Properties

The attacker has two different momentums. One is the first stabbing movement into the abdomen and the second is another stabbing movement, which could be described as a lifting movement by the defender that turns into a semicircular horizontal movement (helped by the defender). We will debate the first stabbing movement. The first stabbing is executed with a slight semicircular movement from a low position held knife, which goes forward but raises up to thrust the defender's stomach.

If we take into consideration that the stabbing knife could describe a quarter of a circle or less (65°) or a little bit less, then we can calculate many

physical qualities such as torque, moment of inertia, power, kinetic energy, and others. All calculations should be done under the angular motion.

Let us calculate the moment (torque) of the attacker's body who is rolled forward by the defender, from Figure 13.18f and 13.18g until when the attacker is in a supine position. The stabbing person (the attacker, who still holding the knife) has a mass of 70 kg. The axis of rotation is considered to be his shoulder. The radius (r) of 0.70 m will be the total arm length of the attacker from the shoulder to the closed fist, which is held by the defender. Then $T = m \cdot g \cdot r$ will be $N \cdot m$ = (686 N, which represents the mass of the body times gravity) (0.70 m), then $T = 480.2\ N \cdot m$.

The moment of inertia (I) = $kg \cdot m^2$ = 70 kg ($0.7\,m^2$) = $34.3\ kg \cdot m^2$. The power (P) = $T \cdot \omega$ ($N \cdot m/s$). For angular velocity (calculating the first stabbing motion), we will use radian. In our case, let us say the stabbing arm could describe approximately 65° angle. The question is how did we reach to this angle estimation? Here is the answer.

The stabbing arm that basically hangs on the vertical line does not start from the vertical line position, but from a 20° approximate angle reported from the vertical line behind the attacker's standing body. Then the stabbing motion continues another 45° angle from the vertical line until the point of stabbing. Adding the two angles described before will add to the 65° angle.

The 65° will have 1.13 rad. Average (v) = 0.8 m/s. (ω) = 1.13 rad/0.8 m/s = 1.41 rad/s. Power (P) = $T \cdot \omega$(480.2 N)(1.41 ω) = 677 $N \cdot m/s$.

So far, the described physical properties were for the attacker. What kind of physical qualities does the defender have? From the time of grabbing the attacker's wrist, the physical qualities are very similar to the previous technique with slight differences. We will stop here for another calculation, for instance, kinetic energy, and we will leave this calculation for the reader.

13.2.5 Nr.3. Arrest Technique with Stabbing and Its Defense

The attacker is on the right side of the figures. He pulls the collar of the defender with his left arm and pushes the knife into the defender's back asking for money. The top white arrow on the attacker's left arm indicates the pulling and the lower arrow on the top of the right arm indicates the pushing with the knife. Initially, the defender lifts both his arms showing his collaboration for the attacker to give up against the attacker (Figure 13.19a).

The defender in order to escape from this attack will turn around 180° clockwise and at the same time drops his right arm. With this movement,

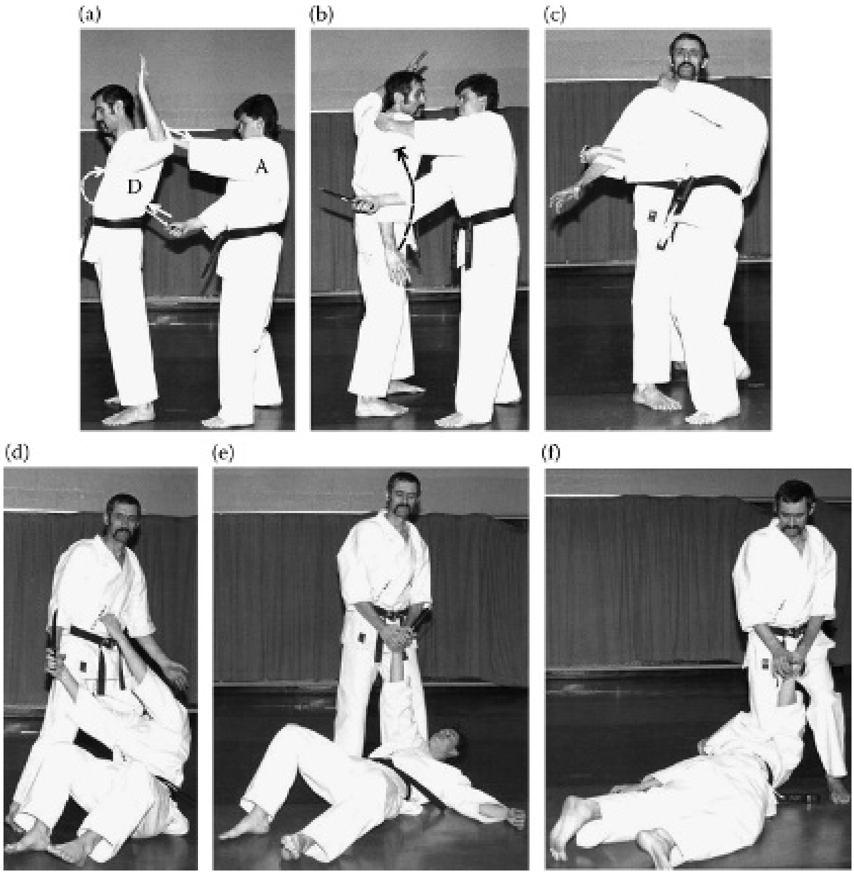


FIGURE 13.19 Arrest technique with stabbing and its defense.

his right arm will be outside of the attacker's knife-holding right arm. The defender should not lose any time and instantly bend his right arm completely, which will close the attacker's right forearm into the defender's elbow pit (Figure 13.19b). The arrow indicates the defender's forearm flexion movement.

Actually the forearm and the upper arm of the defender will be close to each other and this closing position on the attacker's arm can be held for ~2–3 s without difficulty. The attacker has very little chance to pull his knife-holding arm back. The defender continues his defense by turning one more time 90° clockwise, still holding the attacker's arm.

When the defender turns another 90° at the same time, he surrounds the attacker's neck with his left palm from behind and sets his palm on the attacker's chin pulling him backwards, which makes the attacker lose his

balance (Figure 13.19c). The off-balancing of the attacker can be observed very well in Figure 13.19c.

The defender will open his holding position (his flexed right arm) catching the attacker's right arm (Figure 13.19d), which slides down because of the defender's pulling action against the attacker's chin. The defender will reinforce his right hand grabbing position by also grabbing the attacker's arm with his left hand (Figure 13.19e). After this action, the defender turns over the attacker by setting his right knee against the attacker's right shoulder and pushes until the attacker will be on the prone position (Figure 13.19f).

13.2.6 Observation of Physical Properties

In this technique, we will mostly analyze the defender's actions. The attacker uses an attack with a very good force couple. Look at Figure 13.19a where one hand pushes and the other one pulls. Both act in the opposite direction. At first glance, this action of the attacker looks strong and solid; however, he cannot hurt the defender seriously. Only if he pulls back his knife-holding arm can he can stub and hurt the defender.

This action is similar to when you push a nail through a wooden wall, which you hold on the surface of the wall. Logically, the nail will not go through the wall. However, if you hold it at a certain distance from the wall, you have the chance to push the nail into the wall a little bit.

When the defender turns around in the clockwise direction, he could lose his balance; however, after catching the attacker's knife-holding arm in his right elbow pit, he recovers his balance. The defender's turning and catching the attacker's arm must be executed extremely fast. At this time, the attacker still could hold the defender's collar from behind for his balance.

The defender in Figure 13.19e and 13.19f managed to have the attacker's arm extended, which he will use as a lever against the attacker to be immobilized. The correct leverage can be seen in Figure 13.19f, which can be considered as a second class lever, where the axis is on the shoulder of the attacker, and the resistance arm can be considered the knee of the defender, which pushes forward toward the attacker's right shoulder. The force arm is the entire arm of the attacker, which is pulled backward by the defender toward the attacker's left shoulder.

13.2.7 Nr.4. Slashing and Stabbing Attack, Defense with Side Kick

The defense against this attack is extremely effective; however, it is very dangerous. The attacker is on the left side of the figures. Both combatants stand with their left foot forward (Figure 13.20a). The attacker steps

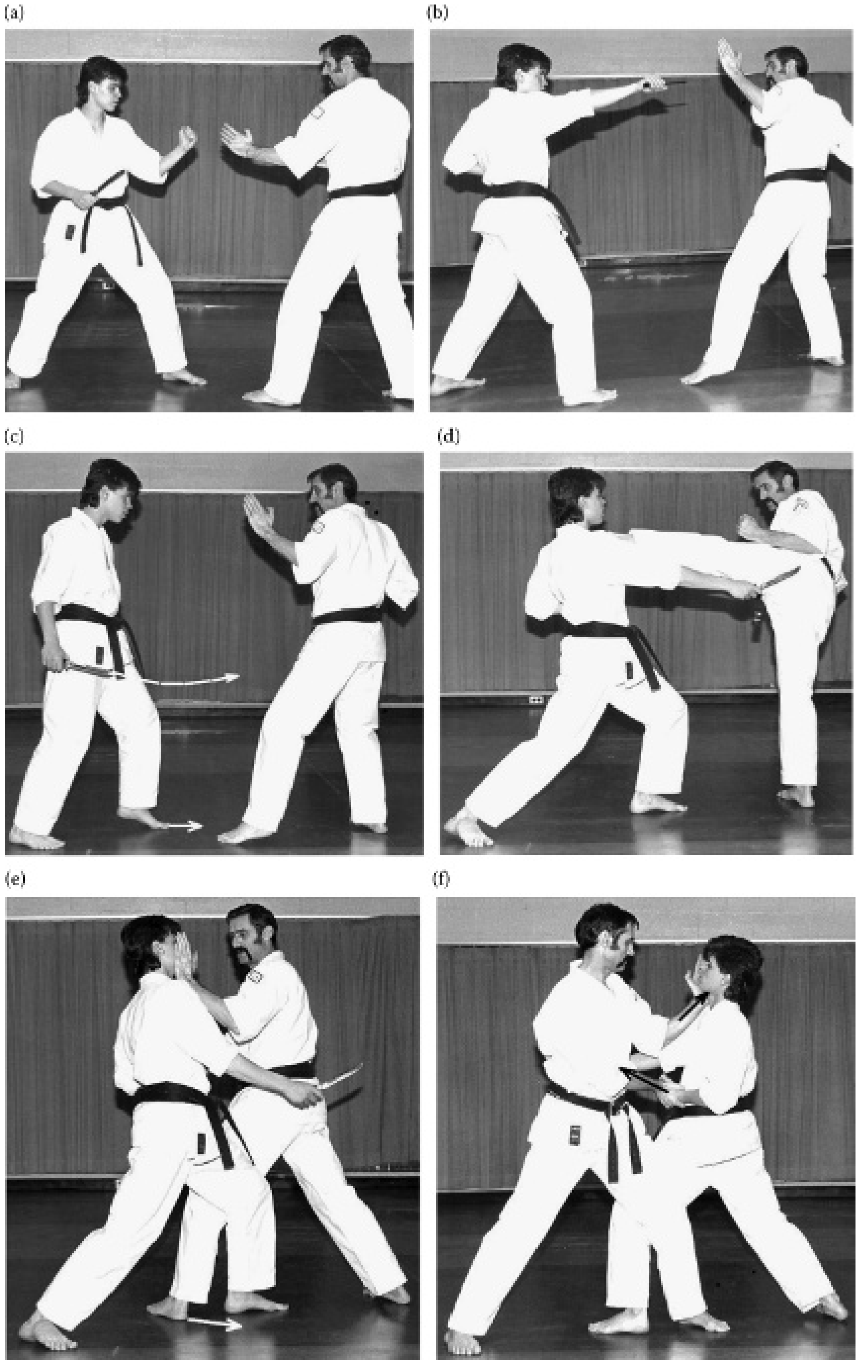


FIGURE 13.20 Slashing and stabbing attack, defense with side kick.

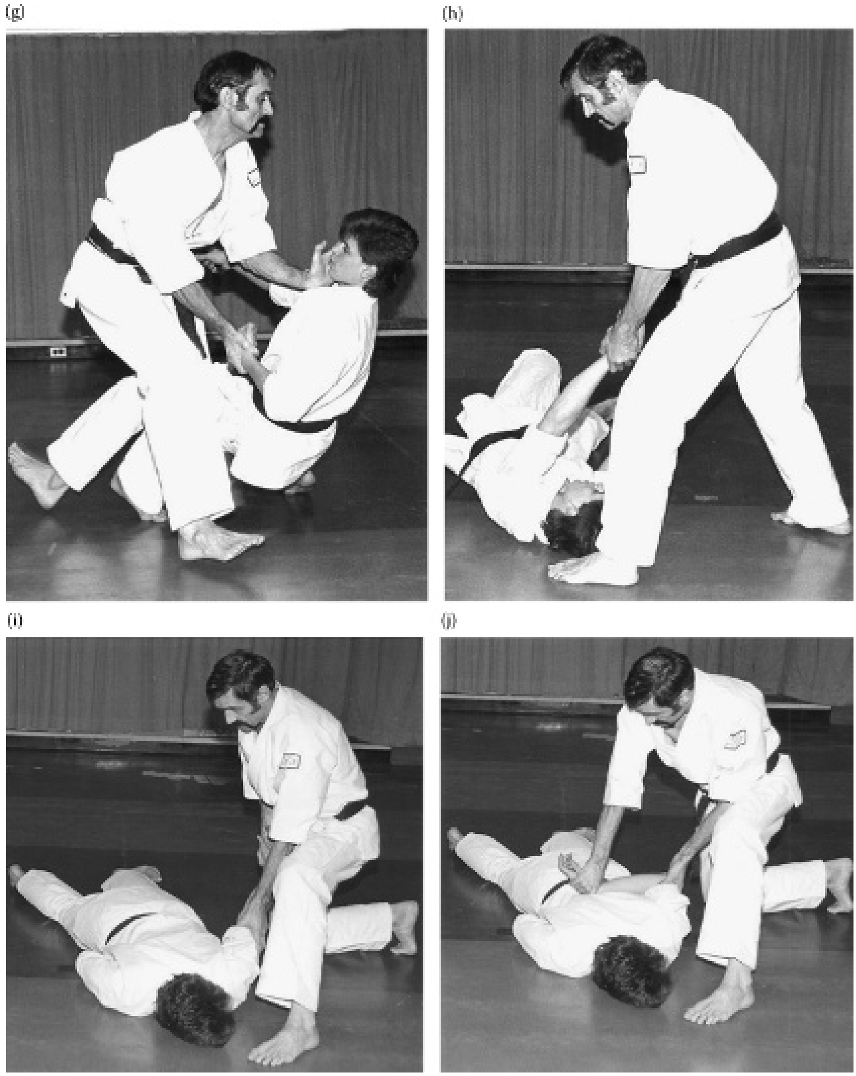


FIGURE 13.20 (Continued.)

forward and tries to slash the defender's left hand. The defender holds his position by sliding back and moving to right (left leg in front) and pulls back his left hand (Figure 13.20b).

The attacker steps forward with his left leg and tries to stab straight into the defender's ribs (Figure 13.20c). The defender slides more backward diagonally to his right with both his legs and at the same time stops

the attack with a left side kick *(Yoko-geri-keage-kekomi)* to the attacker's neck (Figure 13.20d).

This side kick will surprise the attacker. The defender snaps down his kicking leg outside of the attacker's left leg and grabs with his right hand the attacker's left arm at the wrist and pushes the attacker's chin backward and up with the heel of his left palm *(Teisho)* (Figure 13.20e and 13.20f). In Figure 13.20e, the arrow shows a possibility to hook the attacker's leg.

In Figure 13.20f, the defender's left heel of the palm pushes the attacker's chin back and upward as shown with an arrow. In the same figure, the defender's right arm pulls up the attackers' left arm a little bit as shown with an arrow.

After the attacker has been taken down (Figure 13.20g), the defender will continue his counterattack by moving the attacker from a supine position to a prone position (Figure 13.20h).

Figure 13.20i and 13.20j shows the turning over of the attacker's body and fixing his left arm on his back. The defender can order the attacker to give up and release the knife, which is now held under the attacker's chest.

13.2.8 Observation of Physical Properties

The most important physical qualities of the attacker and the defender are their quickness (reaction of speed). The attacker should be able to change his slashing into the thrust attack with a lunging step. The defender in his turn should be able to withdraw quickly and to counterattack with a side kick at the knee of the attacker. The stopping kick can also be a front kick or roundhouse kick and is executed not only to the neck of the attacker but anywhere else. However, if the side kick is executed correctly with sufficient power to the neck of the attacker, then he will be disarmed definitively.

The defender must also be very fast when he stomps his left foot on the ground behind the attacker's left leg (Figure 13.20e). There should not be any hesitation in grabbing the left arm of the attacker, which is grabbed by the right arm of the defender.

Before the take-down is actually executed (Figure 13.20e and 13.20f), the defender can emphasize his take-down with a hooking technique against the attacker's left leg. What is interesting in this technique is that until the end of the disarming technique when the attacker will be on his prone position, he still has the knife in his hand.

Holding the knife all the time will not cause any problem for the defender because during the preliminary take-down execution, the attacker is busy

trying to maintain his equilibrium and later on he will be held in a fixed position inflicted with pain. At the end, the defender can order the attacker to give up/release the knife.

The kinetic energy can be calculated. The attacker has a mass of 70 kg, then $KE_{\text{linear}} = 1/2\ m \cdot v^2$. We can register the velocity from the time when the defender grabbed the left arm of the attacker until the time when the attacker landed down on his buttock. This time can be approximately more than 1 s. We will take an approximate time as 1.5 s.

$$KE_{\text{linear}} = 1/2\ (70\text{ kg})(1.5\text{ s})^2 = 78.75\text{ J.}$$

13.2.9 Summary

Part IV described nine different martial arts. Many of the techniques selected have been described as 3-D motions. Part IV occupied a major part of the book. Each martial art had a short summary, some classification of the techniques described, and also some anatomophysiological considerations about the techniques in case, including effort characteristics, dosage, and occurrence.

Each martial art had biomechanical and technicotactical principles. Each martial art technique had a detailed biomechanical description.

Some techniques focused mostly on the lever component, and others focused on the different mechanical axes of the body in rotation. Part IV described the calculation of the moment of inertia, momentum, power, work, and kinetic energy all related to angular motion.

Each technique had a portion for observation of the different physical properties and their equations related to mechanics or physics. Many technique descriptions focused on different muscular segments and its movements. Each martial art had objectives in which the author gave an opportunity to the reader to answer the questions listed under objectives.

13.3 THE BIOMECHANICS OF THE JAPANESE SWORD (KATANA) DEFENSE

The first edition of this book had no section on Japanese sword art.

Six years after the publication of the first edition, Taylor & Francis contacted me about this second edition. So I am ready to include some information about the vicious Japanese weapon known as Katana.

Basically any cut with the Katana is rotational/angular except the thrust which is a straight linear execution. I will not dissect using physics for the force, velocity, energy and momentum. As an example the

cut with the Katana could be executed from a forward (from up-down, lateral (to left or right) or diagonal cut and some minimal variation. This Subchapter cannot be find in the first edition of the book, however I find important to express my opinion as a martial artist a possibility of defense against a very dangerous weapon.

I will start with a real fact. I tried to defend against this dangerous weapon I reached to conclusion in order not to be hurt, that I had some very slight chance. Here I enumerate the defensive skills (I not even wrote the word "techniques"). Techniques in any other fighting art are those skills which are used by the vast majority of the martial artists and are recognized by experts of the certain martial art/style. Using from Karate the 3 basic distance (Ma) in Japanese for defense or attack.

1. Chika-ma the shortest distance. Arm length distance.
2. Uchi-ma the medium distance. Small step forward or backward distance.
3. To-ma the long distance. A little bit longer then a step distance.

Almost all distance has no advantage however if you are so close to the attacker Chika-ma, then logically the attacker cannot use the sword because the defender will stop the sword not to be pulled out from the scabbard by (Saya in Japanese) the attacker. The most dangerous distance is the medium range Uchi-ma, at this distance the defender has the biggest disadvantage because the attacker can twist his blade, can move back and front, shortly the attacker can do many maneuvers. Using the largest distance To-ma the defender can avoid most of the attacks (swinging with the blade) from the attacker. Top Aikido masters are using only wooden swords, in this case any injury is not fatal and their demonstration of the defense is pre-established (usually a large step during the strike of the attacker),

The big question is what kind of defensive skill will use the defender against any man who swinging savagely his sword? Probably you will stay far from him (use the To-ma) at the long distance. But you want him to be disarmed. You cannot use the Chika-ma distance if you were at the To-ma distance. How do you approach to gain distance and to be able to disarm the lunatic. Myself as an Olympic Fencer I loved challenge, but in short time I realized that there is no safe defense against a Katana attack. If the attacker steps forward and thrust the defender in the chest or stomach

area then the defender has a slight chance to defend himself. I can offer by offering a test of defense or bravery if you want to name it to anybody anytime to be a defender and myself to be the attacker attacking the person with a sharp Katana to defend himself. I have the rules of safety for any person.

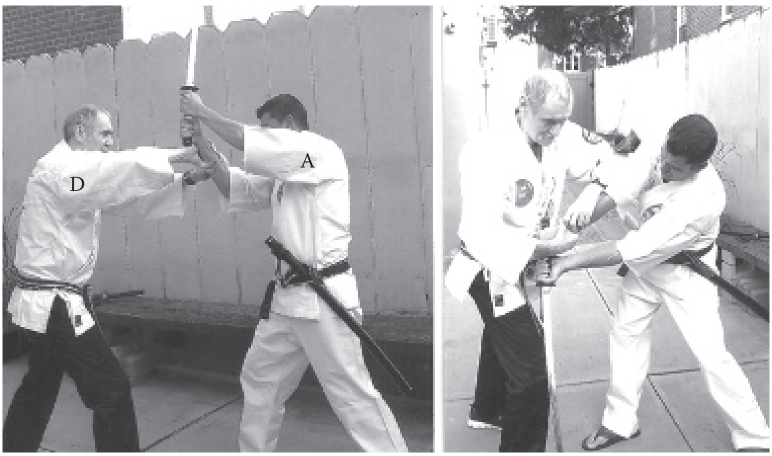
The following figures will demonstrate the possibility of defending against a (*Katana*) and mistakes of the defense.

(a) (b) (c)

Figure b shows a cut from up-down forward. From this position the attacker can cut diagonally too. Figures a and c show cuts sideways against any object including the body of a human being.

The letter D means defender, the letter A means attacker.

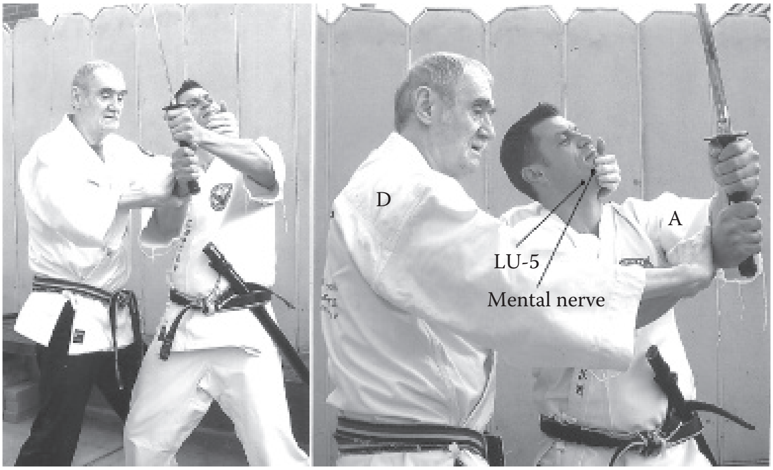
(d) (e)



The defender managed to get close to the attacker and grabbed the attacker's right forearm. From this position the defender can pull both arms of the attacker down and toward to his right side and continue a temporary immobilization (Figure e). From Figure e the defender maneuver the attacker arms by holding them as a balance for the defender and the defender will go behind the attacker and will be ready to take the attacker down.

It is important to state (Figure e) to the reader who can see the opportunity for the attacker to handle in any way his weapon. Please see the blade, it is so close to cut the defender thigh (Figure e).

(f) (g)



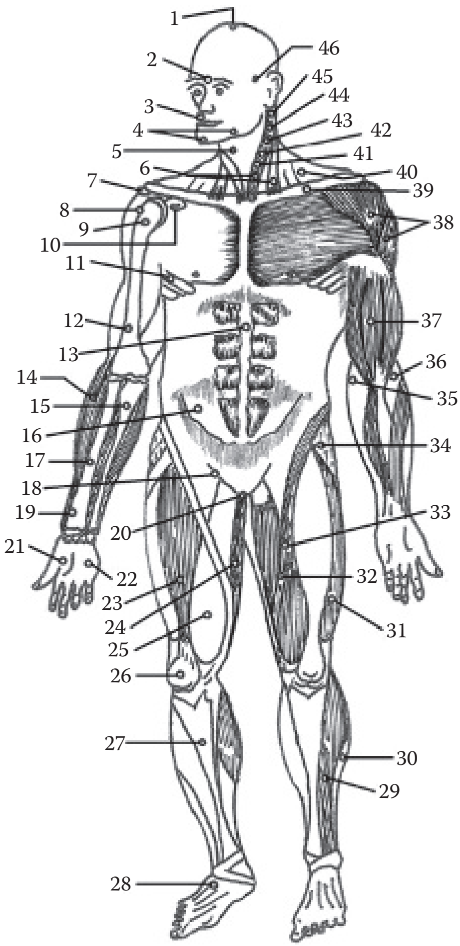
In Figure f the defender has the chance to push the attacker's right knee. In Figure g the defender can use p.p. LU-5 or the mental nerve to emphasize the take down of the attacker.

The reader can see that there is very minimal chance to defend against a sharp (*Katana*). The attacker can twist both his wrists. By doing so he can use the twisting and pulling-pushing his weapon as a kind of lever arm against the defender arms. The attacker's axis for the lever arm is in between his two fists.

Note: Weapons from Europe in general were lighter than the Japanese counterpart. The Japanese sword is made to kill, the European weapons are made to hurt. In a certain army to be British, French, Polish, Hungarian, Spanish etc., the officers had also the lightest saber weapons in order to not kill, but to heart the adversary officer. An officer had to have the ethico-moral and knight fighter attitude.

Appendix A

A.1 MUSCULO-SKELETAL FIGURE REPRESENTING THE MOST IMPORTANT VITAL POINTS: FRONT PART OF THE BODY



1. *Vertex*—dented or fractured skull. Hematoma, faint or death can occur.
2. Between the two frontal sinus lines, in proximity there are the *supratrochlear artery* and *vein*. Effect: Pain by hitting.
3. Above the upper lip is the *facial artery.* Effect: Violent pain by pressing.
4. *Mandible*—Dislocation, faint.
5. *Adam's Apple*. Effect: Faint or death.
6. *Sternocleidomastoid,* both sternal and clavicular head. Pressure should be exerted between the intersections of both muscles. The muscle covers: The carotid artery, internal jugular vein, vagus (Xth) nerve. Effect: By striking can cause immediate death or fainting if pressed.
7. *Acromion* of scapula.
8. *Greater tubercle.*
9. *Lesser tubercle.* Effect for both: Violent pain if pressed.
10. *Coracoid process.*
11. *Serratus anterior muscle.*
12. *Humerus bone.*
13. *Solar plexus* consists of great network of nerves. Effect: Faint, unconsciousness, shock.
14. *Brachioradialis,* covers the superficial radial nerve, lateral antebrachial cutaneous nerve, radial recurrent artery. Effect: Results in violent pain, if pressed.
15. *Ulna.*
16. *Liver,* contains many blood vessels, the most important are: Vena cava (inferior), portal vein (hepatic), hepatic artery, and others. Innervations received from the spine T_1 to T_2. The liver has a major role in the parasympathetic nervous system. Effect: Shock or death.
17. *Radius bone.*

18. *Inguinal ligament*. The ligament covers the external iliac artery and vein which turns to be named femoral artery and vein. Effect: Pain if pressed.

19. Shows the point on the *radius bone* under which is the radial artery. The point for pressure is at 5–5.5 cm distance from the wrist. Effect: Extreme pain and brain damage if the pressure is exerted for a long time or executed repeatedly more than 10 times during a training session.

20. *Groin*—Testicular artery and vein. Effect: Shock, faint, or even death when kicked on one of the testicles and is pushed through the internal spermatic fascia and up against the end of the spermatic cord.

21. *Thenar eminence* (area) covers proper palmar digital arteries and nerves which are located toward the middle of the palm.

22. *Hypothenar eminence* covers common palmar digital arteries and nerves.

23. *Rectus femoris* is on the top of the quadriceps muscle there are many nerve fibers from the cutaneous branches of the femoral nerve. Under the rectus femoris is the *vastus intermedius* which has on it the lateral circumflex femoral artery. Effect: Pain.

24. *Gracilis* muscle.

25. On the top of *vastus medialis* can be found part of the great saphenous vein, accessory saphenous vein and the femoral artery. Effect: Pain, dizziness, faint.

26. *Patella*.

27. *Tibia bone*. Pain if kicked.

28. *Area of the metatarsal bones* which covers the dorsal venous network, dorsal metatarsal arteries and the intermediate, medial dorsal cutaneous nerves. Effect: Pain if stamped, kicked, or pressed.

29. *Tibialis anterior muscle.*

30. *Soleus muscle.*

31. *Vastus lateralis* covers the lateral femoral cutaneous nerve. Effect: Violent pain if kicked.

32,33. *Sartorius muscle*. The two points indicate the exact place where the pressure or kick/strike should be directed. On and around this muscle there are the following: Mostly on the medial part of the muscle is the great saphenous vein, immediate vicinity on the muscle is the femoral artery and the third one mostly toward the lateral part of the thigh is the saphenous nerve. Effect: Pain and dizziness by pressing or kicking.

34. *Fascia lata*.

35. Above the *medial epicondyle* of the *humerus* approximately 1.5 cm distance can be found the *ulnar nerve*. Effect: Pain if pressed.

36. Above the *lateral epicondyle* of the *humerus* can be found: the posterior antebrachial cutaneous nerve, radial nerve, and radial collateral artery. Effect: Pain if pressed.

37. Under *biceps brachii* can be found the *musculocutaneous nerve* and part of *brachial artery*, 1/3rd lower part of the arm. On the top of the muscle is the *cephalic vein*. Effect by hitting on the middle of the muscle: Numb pain.

38. *Deltoid muscle*.

39. *Clavicle bone*. Effect by striking: Fracture.

40. *Trapezius muscle*. Pinch the muscle. Effect: Pain.

41. *Jugular vein*.

42. *Vagus* (Xth) *nerve* is involved with autonomic nervous system of the sensory and motor fibers. Effect by hitting: Faint or death. Effect by pressing: Faint.

43. *Carotid artery*. Effect: Similar to previous one.

44. *Posterior auricular vein*. Effect: Faint or shock.

45. *Head of mandible bone*. Great auricular nerve located just at the head of mandible. Effect by striking, kicking: Broken bone and KO.

46. *Temple area* contains the anterior and posterior deep temporal arteries, auriculotemporal nerve and superficial temporal artery and vein. Effect by hitting: Dizziness, faint (shock). If the strike is hard enough, the subject cannot open his mandible or opens with pain.

Note: Under Section A.1, the author described in more detail some of the anatomical parts (region) and vital points and different actions such as striking, pressing, and kicking and their effects. Those anatomical parts and regions included descriptions mostly about nerves, arteries, and veins and their relations to the actions exerted by one participant (attacker).

In some parts the descriptions were simply written about the anatomical part with no explanation. Those with no explanation meant to be only for the reader to be accustomed with the anatomical site (not related to any action). In some parts of the description it has been written clearly such as "hard blow" or "pressing," and so on, indicating the actions and also the reactions from such an attack. It is obvious that pressing, hitting, and kicking can be exerted differently by the attacker and also it is obvious that the reaction can be different too.

In many parts of the explanations it was not written such as muscle or bone, and so on. The reader must have a substantial knowledge to recognize that certain anatomical part which represents a bone, muscle, vein, or something else. Section A.2 will follow the same kind of descriptions.

In some parts of the descriptions the word "action," "effect," or "reaction" is not written for example, 4. Mandible—Dislocation, feint. Here the reader should know that this is about a strike or kick.

A.2 BACK PART OF THE BODY

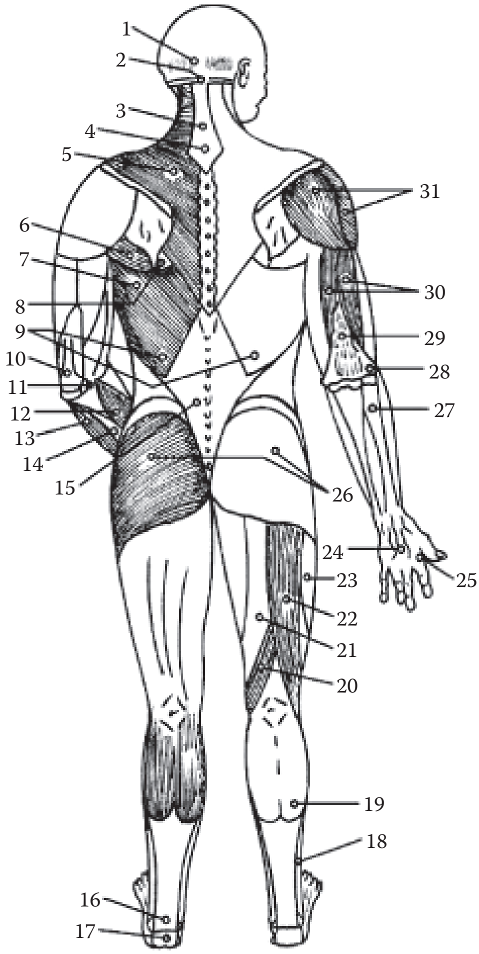
The back part of the body when struck by a sharp object can cause violent pain.

1. *Occipitalis* (area) is vastly innervated and also has a complex artery and vein ramification. The occipital nerve situated almost in the middle of the occipital area, the artery and vein are situated a little bit toward the lateral part of the occipitalis area. Affected by a hard strike causes an immediate collapse, fainting and even death.

2. *Base of the skull* (nuchal line). There are three nuchal lines: Highest, superior, and inferior nuchal line. The highest is palpable. Affected by striking is similar to occipitalis.

3. *Neck* (nape) general area. All the nerves from the head to the spine and vice-versa can be found in this area. Effect by blow: Fainting or death.

4. The 7th *cervical vertebrae*. Effect by blow: Collapse; fainting or even death.



5. *Trapezius.*

6. *Teres major.*

7. *Latissimus dorsi.*

8. *Rhomboid.*

9. *Kidneys* including the renal artery and vein and their ramification. Effect by strike: Subject could collapse and will urinate blood.

10. *Humerus.*

11. *Medial epicondyle.*

12. *Flexor carpi ulnaris.*

13. *Extensor digitorum.*
14. *Extensor carpi ulnaris.*
15. *Thoraco-lumbar fascia.*
16. *Achille's tendon.*
17. *Calcaneus.*
18. *Soleus.*
19. *Gastrocnemius.* If pressed hard or kicked. Effect: Violent pain.
20. *Semimembranosus.*
21. *Semitendinosus.*
22. *Biceps femoris*. On the back of the thigh the posterior femoral cutaneous nerve can be found. From the middle part down is the accessory saphenous vein and the popliteal artery. Along the entire thigh the widest nerve (sciatic) also can be found. Effect: If kicked cause pain.
23. *Vastus lateralis.*
24. *Back of the palm.*
25. The vital point shown in the figure, the exact point where the pressure should be exerted, which should be directed between the 1st and the 2nd metacarpal bones. The *point of pressure* must be at the base of the 2nd metacarpal bone where the dorsal digital nerve of the point finger can be found, which is a prolongation of the radial nerve. In close proximity is the tiny branch of the radial artery. Pressing this point results in extreme pain. This pressing technique is extremely useful against a very strong grip from the opponent.
26. *Gluteus maximus.*
27. *Radius.*
28. *Lateral epicondyle of the humerus.*
29. *Triceps tendon*. Effect is pain if it is rubbed or hit.
30. *Triceps brachii.*
31. *Deltoideus.*

Appendix B

B.1 KINEMATIC (MUSCULAR) CHAINS OF DIFFERENT TECHNICAL EXECUTIONS

Figures B.1 and B.2 shown represent the agonist and antagonist muscles. The black spots represent the agonist muscles. The parallel lines represent the antagonist muscles, except the lines on the chest and the back of the figures.

Observe the differences of the agonist and antagonist muscles between the Figure B.1a and B.1b.

1. The *deltoid* muscle; anterior fibers flex and medially rotates the humerus.

2. The *biceps brachii* flexes the forearm.

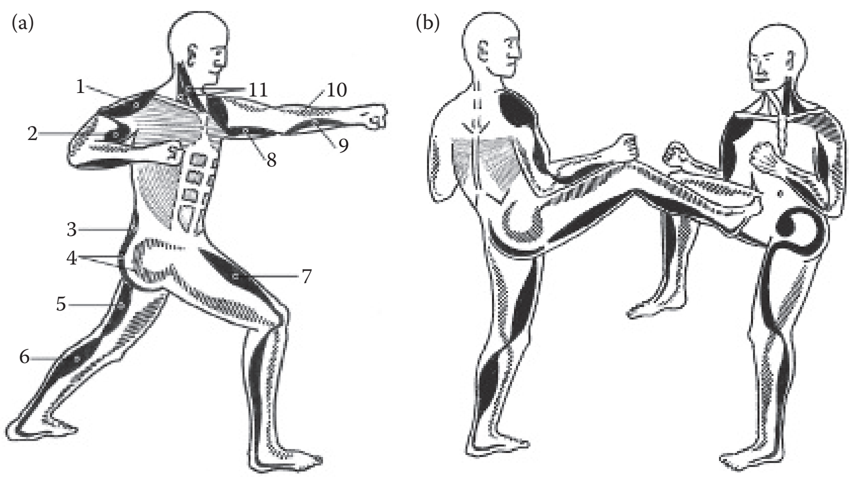


FIGURE B.1 (a) Shows the reverse punch (*Gyaku-zuki*). (b) Shows the front kick (*Mae-geri*).

3. The *multifidus* at the lower back extends the trunk, while *rotators* assist in extension.

4. The *gluteus maximus* extends the trunk.

5. The left thigh *bicep femoris* flexes the calf.

6. The *gastrocnemius* executes the plantar flexion of the ankle and assists the flexion of the knee. The plantar flexion is important for the foot to be planted firmly on to the ground.

7. The *quadriceps femoris* extends the calf. The right thigh is in a flexed position and in this case the agonist muscle should be the *bicep femoris* which flexes the calf.

   The reality is the following:

   In Figure B.1a, even if the thigh is bent, the muscle action of the thigh is reduced to a simple tension, by supporting the upper body weight. The main muscular action is not on the thigh, but is on the lower back of the karateka where the gluteus maximus and multifidus exert a strong extension, and the muscles of the rotators also assist in the extension of the trunk.

8. The *tricep brachii* extends the forearm.

9. The *palmar side of the forearm*; flexors of the wrist, flexes the fingers into a fist position.

10. The *posterior side of the forearm* represents the extensors of the fingers. In Figure B.1a, the forearm muscles are rotated from the supine to the prone position. On the top of the forearm the *brachioradialis muscle* can be seen.

11. The *sternocleidomastoideus*, sternal and clavicular fibers both rotate the head to the opposite side.

Note: Usually if an agonist muscle covers a long bone such as the humerus, then the antagonist muscle is found on the opposite side of the bone. This role of course can be reversed. For example, if the biceps brachii is considered as an agonist muscle, and then the triceps brachii as the antagonist muscle. An extensor muscle is agonistic to a flexor muscle, for example, the biceps and triceps muscles are agonistic pairs.

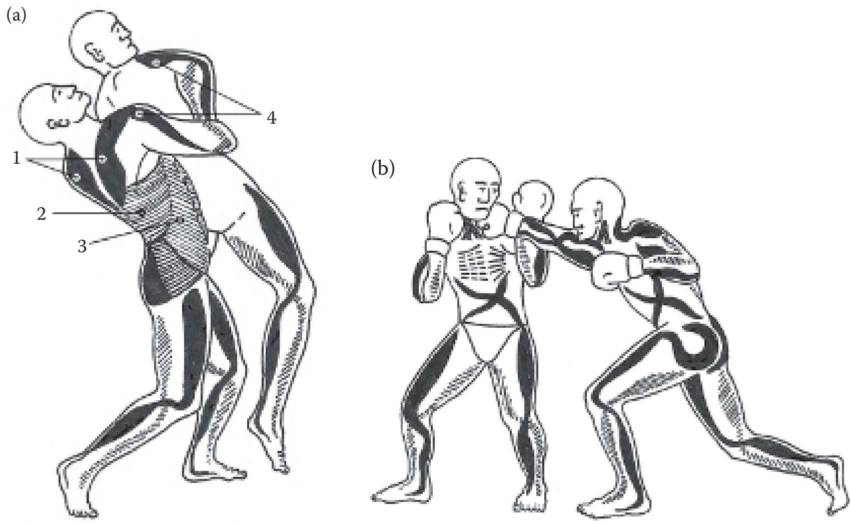


FIGURE B.2 (a) Shows the technique of supplex. (b) Shows a high cross boxing technique.

Synergist muscles can be found on and around the active agonist muscle. Consulting Figure B.2a and B.2b, the reader should realize that when a position by a muscle action is changed, then the role of the agonists and/or antagonist muscles changes too.

1. *Trapezius* muscle draws head back and to the side, rotates scapula.
2. *Latissimus dorsi* muscle adducts, rotates, and extends the arm.
3. *Obliquus externus abdominis* muscle compresses the abdomen.
4. *Deltoideus* muscle raises and rotates the arm.

Appendix C

C.1 ESTABLISHING THE CENTER OF MASSES (CoM) OF TWO KARATEKA BEING IN THE POSITION OF *SEMI-PERMANENT OR PERMANENT/CONTACT LINK,* DESCRIBED IN THE SUMMARY OF PART IV

Following this page Section C.2 shows the procedure how to find out each body segments CoM, the calculation of the masses, and the position of the total mass of the two karateka. Section C.3 shows four figures that follow the same procedure as Section C.2, without showing the lines seen in Section C.2.

This is a 2-D calculation. Using the 3-D calculation would be more precise.

The author established two Y coordinates and one X coordinate. The Y coordinates have been established to the farthest distance of each karateka. For karateka (A) the "Y" line has been established at the right elbow point, where the Y is perpendicular to the X line. For the karateka (B) the "Y1" line is at the end of his right fist. There is only one X coordinate because relatively both karateka stand on the same line.

The calculation of the body segments relative weights in kilograms we used Table 9.1 from Hay (1993). We did not use the decimals; instead we rounded up the decimals, for example, 0.50 to full number(s) 1.00. Eliminated the decimals, for example, under 1.50 to full number(s) 1.00. Both karateka have 70 kg body mass.

In establishing the center of masses (CoM) of the body segments we used Figure 9.4 from Dempster W.T. (1955). The decimals were not used and proceeded just how we did with the body segments weight. The equation we use is: CoM (total body) = *mass* of a body part(s) times *position* of the body part divided by *total masses.*

In our case of many body segments the CoM (total body) for the X coordinate = $(m1)\ (x1) + (m2)\ (x2) + \cdots / (m1) + (m2) \cdots$ CoM (total body)

for the Y coordinate follows the same procedure which was shown above. The total reference point for both body masses and their distance we have the point “0” which is at the lowest left corner of the figure.

See the equations in Section C.2 for Figure C.1, showing the general CoM of the two karateka in combat position.

Note: H = head, TR = trunk, RUA = right upper arm, LUA = left upper arm, RFA = right forearm, LFA = left forearm, RTh = right thigh, LTh = left thigh, RCa = right calf, LCa = left calf. We are not using the hands and feet. The trunk does not include the pelvis region.

The masses of the body segments: Head = 5 kg, Trunk = 35 kg, Upper arm = 2 kg, Forearm = 1 kg, Thigh = 7 kg, Calf = 3 kg. All these segments should represent a man of 70 kg mass, including both sides of the body, however, excluding the feet and the hands minus the decimals will give us 66 kg. Both karateka have a 70 kg mass.

The $x1$, $x2$, $x3$ … refer to the positions of the CoM of each body segment, $m1$, $m2$, $m3$ … refer to each body segment mass; however, in our equations the author uses **“m”** for meter instead of **x**, and uses **“kg”** for kilogram for mass.

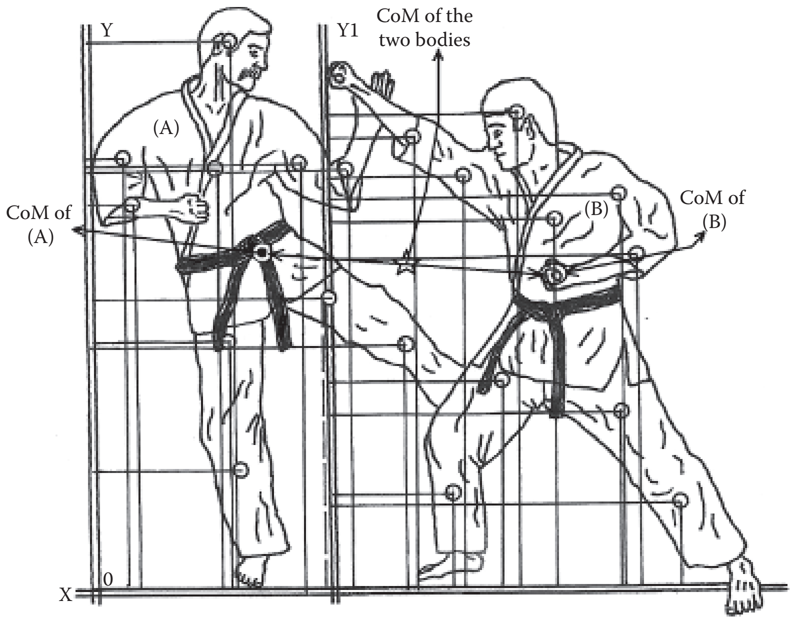


FIGURE C.1

In Figure C.1, the circles on both bodies represent the actual CoM of the body segment in case. The multiplication sign between both bodies represents the CoM of the two bodies.

C.2

Here are the computations for Figure C.1.

Equations for body (A) for the "Y" vertical line:

$$\begin{aligned}&(\mathrm{H} = 0.026\text{ m} \times 5\text{ kg} = 0.13) + (\mathrm{RUA} = 0.007\text{ m} \times 2\text{ kg} = 0.014)\\ &\quad + (\mathrm{LUA} = 0.039\text{ m} \times 2\text{ kg} = 0.078) + (\mathrm{TR} = 0.024\text{ m} \times 35\text{ kg} = 0.84)\\ &\quad + (\mathrm{RFA} = 0.008\text{ m} \times 1\text{ kg} = 0.008) + (\mathrm{LFA} = 0.048\text{ m} \times 1\text{ kg} = 0.048)\\ &\quad + (\mathrm{RTh} = 0.026\text{ m} \times 7\text{ kg} = 0.182) + (\mathrm{LTh} = 0.045 \times 7\text{ kg} = 0.315)\\ &\quad + (\mathrm{RCa} = 0.028\text{ m} \times 3\text{ kg} = 0.084) + (\mathrm{LCa} = 0\ .057\text{ m} \times 3\text{ kg} = 0.171)\\ &= 1.87/66\text{ kg} = \mathbf{0.028\ m + kg}\end{aligned}$$

The 0.028 (m + kg), represents the total CoM distance from the Y vertical line.

Equations for body (A) for the "X" horizontal line:

$$\begin{aligned}&(\mathrm{H} = 0.0101\text{ m} \times 5\text{ kg} = 0.0505) + (\mathrm{RUA} = 0.081\text{ m} \times 2\text{ kg} = 0.162)\\ &\quad + (\mathrm{LUA} = 0.080\text{ m} \times 2\text{ kg} = 0.16) + (\mathrm{TR} = 0.079\text{ m} \times 35\text{ kg} = 2.765)\\ &\quad + (\mathrm{RFA} = 0.072 \times 1\text{ kg} = 0.072) + (\mathrm{LFA} = 0.078\text{ m} \times 1\text{ kg} = 0.078)\\ &\quad + (\mathrm{RTh} = 0.047\text{ m} \times 7\text{ kg} = 0.329) + (\mathrm{LTh} = 0.055\text{ m} \times 7\text{ kg} = 0.385)\\ &\quad + (\mathrm{RCa} = 0.023\text{ m} \times 3\text{ kg} = 0.069) + (\mathrm{LCa} = 0.045\text{ m} \times 3\text{ kg} = 0.135)\\ &= 4.20/66\text{ kg} = \mathbf{0.063\ m + kg}\end{aligned}$$

The 0.063 (m + kg), represents the total CoM distance from the "X" horizontal line.

The 0.028 and the 0.063 unification points represent the body (A) total CoM.

Equations for body (B) for the "Y1"vertical line:

$$\begin{aligned}&(\mathrm{H} = 0.035\text{ m} \times 5\text{ kg} = 0.175) + (\mathrm{RUA} = 0.025\text{ m} \times 2\text{ kg} = 0.050)\\ &\quad + (\mathrm{LUA} = 0.053\text{ m} \times 2\text{ kg} = 0.106) + (\mathrm{TR} = 0.041\text{ m} \times 35\text{ kg} = 1.435)\\ &\quad + (\mathrm{RFA} = 0.015\text{ m} \times 1\text{ kg} = 0.015) + (\mathrm{LFA} = 0.056\text{ m} \times 1\text{ kg} = 0.056)\\ &\quad + (\mathrm{RTh}\ 0.032\text{ m} \times 7\text{ kg} = 0.224) + (\mathrm{LTh} = 0.054\text{ m} \times 7\text{ kg} = 0.378)\\ &\quad + (\mathrm{RCa} = 0.022\text{ m} \times 3\text{ kg} = 0.066) + (\mathrm{LCa} = 0.064\text{ m} \times 3\text{ kg} = 0.192)\\ &= 2.69/66\text{ kg} = \mathbf{0.040\ m + kg.}\end{aligned}$$

The 0.040 (m + kg), represents the total CoM distance from the "Y1" vertical line.

Equations for body (B) for the "X" horizontal line:

$$
\begin{aligned}
&(\mathrm{H} = 0.089\ \mathrm{m} \times 5\ \mathrm{kg} = 0.445) + (\mathrm{RUA} = 0.077\ \mathrm{m} \times 2\ \mathrm{kg} = 0.154)\\
&\quad + (\mathrm{LUA} = 0.074\ \mathrm{m} \times 2\ \mathrm{kg} = 0.148) + (\mathrm{TR} = 0.068\ \mathrm{m} \times 35\ \mathrm{kg} = 2.38)\\
&\quad + (\mathrm{RFA} = 0.085\ \mathrm{m} \times 1\ \mathrm{kg} = 0.085) + (\mathrm{LFA} = 0.062\ \mathrm{m} \times 1\ \mathrm{kg} = 0.062)\\
&\quad + (\mathrm{RTh} = 0.039\ \mathrm{m} \times 7\ \mathrm{kg} = 0.273) + (\mathrm{LTh} = 0.033\ \mathrm{m} \times 7\ \mathrm{kg} = 0.231)\\
&\quad + (\mathrm{RCa} = 0.018\ \mathrm{m} \times 3\ \mathrm{kg} = 0.054) + (\mathrm{LCa} = 0.016\ \mathrm{m} \times 3\ \mathrm{kg} = 0.048)\\
&= 3.88/66\ \mathrm{kg} = \mathbf{0.058\ m + kg.}
\end{aligned}
$$

The 0.058 (m + kg), represents the total CoM distance from the "X" horizontal line.

The 0.040 and the 0.058 unification point represent the body (B) total CoM.

In Figure C.1, the star sign between the two karateka represents the CoM of both karateka in action.

Note: Body (A) and body (B) CoM have discrepancy of (+1 mm and –2 to 4 mm) in Figure C.1. Scale, the original sketch was larger than the one in our book page.

In Figures C.2 and C.3, the procedure of the equations are identical with Figure C.1. Here the reader can see the vertical "Y" and horizontal "X" lines which indicates the distance of the two legs of the karateka in case. If the two legs are not on the same line, then the reader can see two X lines, one for the karateka which stands approximately in the same line and the other one where karateka clearly has both legs apart, then the "X" line is between the karateka's two legs.

Description of the techniques: Karateka (B) attacks with a simple punch (*Mae-te-zuki*), and then karateka (A) defends with the open sliding palm block (*Te-nagashi-uke*) and at the same time he kicks the thigh of the attacker (B) making him to lose balance, Figure C.1.

(A) continues his counter attack by hitting the (B) left carotid artery with a right hand strike (*Haito-uchi*) and at the same time introduce his right thumb into the (B's) Karate-gi (outfit) and grabs the collar, Figure C.2a. At this time A squatted down by bending his knees and then introduces his left forearm between the two thighs. In the meanwhile he holds B's collar, Figure C.2b.

(A) lifts his opponent up and throws him down, Figure C.3a. (A) is ready to execute a stamping kick on (B's) body, Figure C.3b.

C.3

The double circles represent each body CoM.

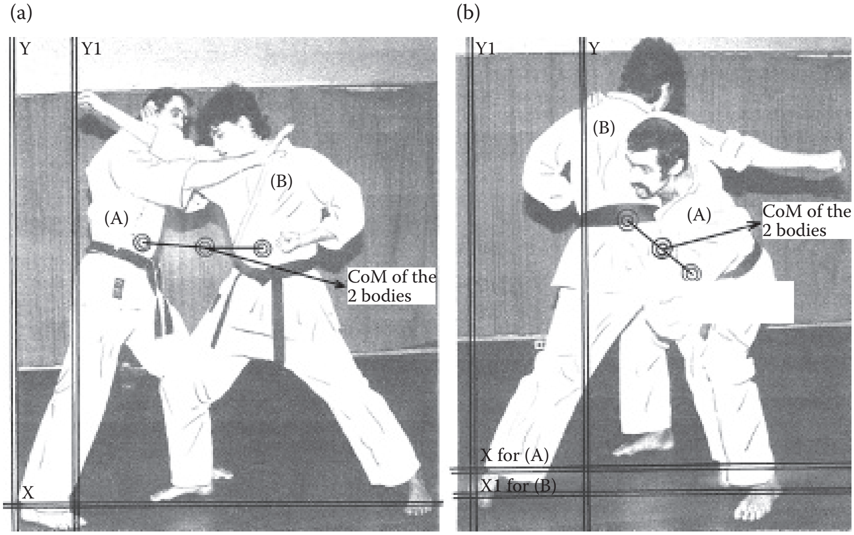


FIGURE C.2

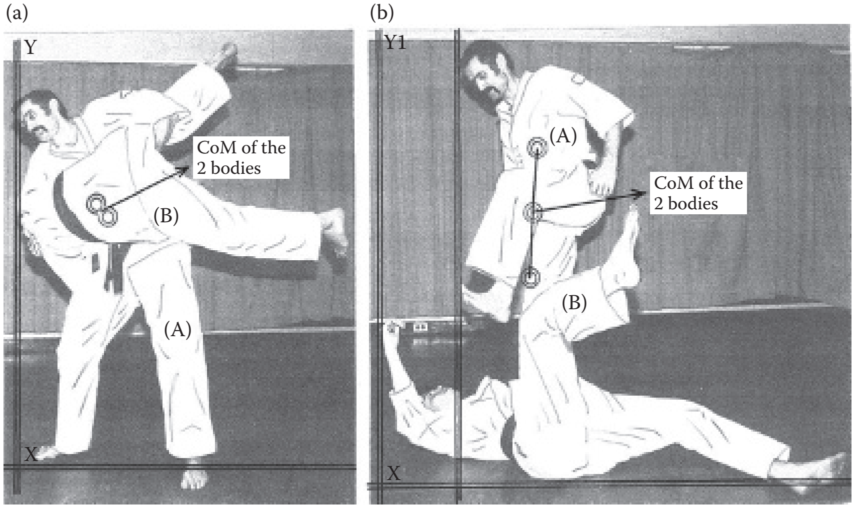


FIGURE C.3

Appendix D

D.1 STANDARD INTERNATIONAL (SI) UNITS, SYMBOLS, PHYSICAL PROPERTIES, AND QUANTITIES

Note: A *physical property* is any characteristic of an object or substance that can be *measured* or *perceived* without changing its *identity.* In this book, the physical properties of an object are defined traditionally in a Newtonian sense. A *physical quantity* is a physical property that can be quantified by measurement. Separation of abbreviated SI units which involves combined quantities, such as kg · m² for moment of inertia; a centered dot (·) or a short hyphen (-) are accepted; however, a decimal point (.) is also acceptable.

Observe the lettering of the symbols which are in italics or normal.

Quantity/Property	Definition	Symbol	SI Unit
Angular acceleration	Angular velocity/ time	α	rad/s^2
Angular impulse	Newton · meter · second	ΔL	N · m · s or kg · m^2/s
Angular momentum	Kilogram · meter squared/second	L	kg · m^2/s or $m \cdot r^2 \cdot \omega$
Angular velocity	Angle/time	ω	rad/s
Energy (potential) (*PE*)	Mass · acceleration of gravity · height	J (joule)	$m \cdot g \cdot h$
Energy (linear kinetic)	Mass · velocity squared	J (joule)	$KE = 1/2\ m \cdot v^2$ or 1/2 kg · (m/s^2)
Energy (angular kinetic)	Moment of inertia · angular velocity squared	J (joule)	$KE_{ang} = 1/2\ I \cdot \omega^2$ or $1/2\ (m \cdot r^2)\omega^2$ or kg · m^2/s^2

continued

(Continued)

Quantity/Property	Definition	Symbol	SI Unit
Force (F)	Newton (mass · acceleration)	N	kg · m/s² or $F = m \cdot a$
Linear acceleration	Meter/second squared	a	m/s^2
Linear impulse	Newton · second	J	N · s or kg · m/s
Linear momentum	Kilogram · meter/second	p (mv)	kg · m/s or N · s
Linear velocity (speed)	Meter/second	v	m/s
Moment of inertia	Kilogram · meter squared	I	$kg \cdot m^2$
Power (P)	Watt	W	J/s or N · m/s
Pressure (p)	Pascal	Pa	N/m^2
Torque or moment	Newton · meter	T or τ	N · m
Work (W)	Force · displacement	J (joule)	$F \cdot s \cos \theta$
Work angular	Torque · angular displacement		$T \cdot \theta$

Base Units in the SI System

Dimension	Symbol	Unit
Area	A	m^2
Angular displacement	θ	$s = r\theta$
Density	p	m^3
Linear displacement	d or s	Meter (m)
Length	l	Meter (m)
Mass	kg	Mass (m)
Time	t	Second (s)
Volume	V	Cubic meter (m^3)
Watt	W	J (joule/s)

Answers to Study Questions

CHAPTER 8

1. The initial velocity of the kicking foot is (v_i) = 0.

   - The final velocity attained by the kicking foot is (v_f) = 12.5 m/s.
   - Time to attain this velocity is (t) = 0.02 s.
   - Acceleration of the kicking foot is (a) = ($v_f - v_i$)/t = [(12.5 m/s–(0), constant acceleration]/0.02 s = 625 m/s^2. This assumes constant acceleration throughout the movement.
   - Then the contact force given by the foot is $F = m \cdot a$ = (1.28 kg) (625 m/s^2) = 800 N.

   Here the force of impact is also equal to contact force given by the foot. Then force of impact is 800 N.

2. Yes it has momentum; however, the object not necessarily must have constant speed in order to have momentum.

3. The impact is a force (N) and it is specific for forces involving a short time period.

   - The impact $F = m \cdot \mathrm{d}v/\mathrm{d}t$, where the d$v$ is the change (Δ) in v, dt = the interval time.
   - The impulse (J) = N · s is not a force; it is an integral of force over time. During an impact the force deals with acceleration and possible changes of effective mass. Impulse changes the momentum specifically the velocity.

4. An object with less mass can have the same momentum, because its velocity is higher as $p = m \cdot v$. These two qualities are inversely proportional and compensate each other.

5. If an object is moving, then it has momentum and because it is moving it has kinetic energy. In this case the object has also mechanical energy.

6. A stationary object has no momentum and has no kinetic energy; however, it has potential energy and thus has mechanical energy.

7. Impulse occurs during a collision. At the time of impact there must be a force which occurs under a short or long time. The result is the impulse.

8. During an impact there is a net force $F = \text{kg(m/s)}^2$ which endures some amount of time to cause an impulse. This impulse acts upon the object to change its momentum.

9. This is a tricky question; we know that an elastic object deflects another object and tends to maintain its original shape. On the other hand, the inelastic object does not deflect the other body. The answer is that an inelastic object will suffer damage. For example, a billiard ball (elastic) thrown at a car (inelastic).

10. The kinetic energy is conserved in an elastic collision. A collision where a total or partial kinetic energy is lost or transferred into other kind of energy, for example, heat energy, is named inelastic collision.

11. The Judoka A's potential energy from the base level is (U) or $PE = m \cdot g \cdot h$, where $m = 80$ kg, $g = 9.8$ m/s^2, $h = 1.5$ m. This can be calculated when the shoulder is taken as a reference level. Then $PE = (80)\ (9.8)\ (1.5) = 1176$ J. We can say that the change in the potential energy of a Judoka A is $PE\Delta = m \cdot g\ \Delta h$. When the Judoka B throws the Judoka A, then we speak about KE. Suppose that the throwing velocity is an average 0.6 m/s. Then the Judoka A's $KE = 1/2m \cdot v^2 = 1/2\ (80\text{ kg})\ (0.6\text{ m/s})^2 = 14.4$ J.

12. Kinetic energy (KE) $= 1/2m \cdot v^2 = 1/2\ (0.25\text{ kg})\ (18\text{ m/s})^2 = 40.5$ J or $\text{N} \cdot \text{m}$.

13. Because you lift a mass against the force of gravity you must multiply the mass with the gravity, where we use the weight $= m \cdot g = 70$ kg

(9.8 m/s^2) = 686 N. Then using the work equation $(W) = F \cdot s$, s = displacement. [N (686)] (1.2 m) = 823.2 J.

14. $P = Work/time = F \cdot s/t$ = (80 kg) (1.2 m)/2 s = 48 W or J/s.

15. Both physical qualities deal with mass and velocity; however, the equations say that the *KE* is more effective, because the velocity is squared.

16. Answer (a) if the mass is greater, then the *PE* is greater. (b) If you are far from the Earth where the force of gravity is less, then the *PE* is less. The answer (b) is mostly hypothetical because the *PE* used by a human is mostly involved at the top of the earth and not in the air. (c) If you are on the Earth and increase the distance from the Earth to a given point, then the *PE* becomes greater.

CHAPTER 9

1. The total force is calculated as a torque: (85 N) (0.78 m) = 66.3 N · m. This calculation is correct only when the blocking arm just blocks, as a "shield" (does not hit), the attacking arm. If the blocking arm is an "attack-block," then the opposing blocking arm force must take into consideration, then the 85 N will be more by adding the opponent's blocking force. The total distance is irrelevant (0.37 m) for torque calculation. The total distance would be changed if we calculate the angular work, where $W = T \cdot \theta$. By having a shorter distance θ must be counted. At this time we are not interested in these calculations.

2. T = N · m = 125 × 0.5 = 62.5 N · m.

3. We should use radians as a standard for international units. As a remainder 1 rad = 57.3° and 6.28 rad = 360°, or one revolution. An advanced Aikidoka can perform this technique in about 2 s/1 revolution. The Aikidoka will perform this technique in about a half revolution. 1/2 revolution = 1 s, according to the question explained in Chapter 9. If the Aikidoka rotates the opponent for a half revolution, then the angular velocity will be equal to π, which is, ω = 3.14 rad/s.

4. $I = \Sigma m \cdot r^2$ = (1/12 = 0.083) (2 kg) (1 m)^2 + (1/12 = 0.083) (2 kg) (1 m)^2 = 0.332 kg m^2. For the moment of inertia calculation we choose a thin rod with the axis at the center of rod.

   $L = I \cdot \omega$ = [(I) 0.332 kg · m^2] × 8 rad/s = 2.65 kg · m^2/s.

5. a. To calculate the moment of inertia we know the equation which is $I = \Sigma\, m \cdot r^2$; however, we use the following equation according to moment of inertia of uniform bodies of various shapes. Then the rotating arm is considered as a thin rod where the axis of rotation has a perpendicular line to the rod and it is at the end of the rod (at the shoulder vertical line down).

   - Moment of inertia (I) = 1/3 $m \cdot l^2$. The m = 3.50 kg, l (r) = 0.7 m. Then I = 0.33 (3.50) (0.7^2) = I = 0.56 kg · m^2.
   - Angular momentum (L) = $I \cdot \omega$ = [(I) 0.56] (rad/s) = [0.56] (3.14 rad/0.9 s) = 1.94 kg · m^2/s. In terms of Newtons we have: (3.5 kg) (9.8 m/s^2) = 34.3 N.
   - Torque *(T)* = N · m = (34.3 N) (0.7 m) = 24 N · m.

   b. (I) = Use the original formula which is: *(I)* = $\Sigma\ m \cdot r^2$ = (3.50 kg) (0.35 m^2) = 0.42 kg · m^2.

   (L) = $I.\omega$ = 0.42 × 3.14/0.9 = 1.46 kg · m^2/s. The 0.9 s represents an average velocity.

   (T) = (34.3 Ng) (0.35 m) = 12 N · m.

6. The radial force $F_{\text{radial}} = m \cdot v^2/r.$ Then (70 kg) (0.3 s)^2/0.156 m = 40.38 N.

Glossary

Note: The Glossary does not contain a detailed explanation of muscles, joints, bones, connections, and parts of physics. However, many of these notions have been described in the book.

A-band: A dark band striated muscle, contains actin and myosin filaments which is located in the center of the sarcomere.

Abduction: A body segment movement away from the midline of the body.

Acceleration: The rate of change in velocity which occurs over a time interval. Expressed as m/s^2.

Acetabular fossa: A rounded depression located in the pelvis, which serves as the attachment point for the femur head onto the acetabulum.

Acetabular labrum: A rim-shaped socket on the exterior part of the acetabular fossa. It serves the femur head to be more stable.

Acetylcholine (ACh): A neurotransmitter that transmits excitation signals at the neuromuscular junction.

Actin: A thin muscle filament which causes muscle contraction. It has a chemical interaction with the thicker myosin filament.

Action potential: A rapid change from the resting potential to depolarization status. During this extremely short time the electrical potential inside the membrane becomes (temporarily) positive with respect to the outside of the cell membrane.

Active movement: It is produced by the subject's own muscular activity.

Actomyosine: The combination of actin and myosin molecules in a muscle fiber. Upon excitation, these molecule fibers shorten without changing their volume and thus cause contraction of the muscle.

Adam's apple: The laryngeal prominence formed by two laminae of the thyroid cartilage.

Adduction: A body segment movement toward the mid-line of the body.

Adenosine diphosphate (ADP): A compound of adenosine containing two phosphoric acid groups. This substance is produced during muscle contraction. It is reformed when the muscle relaxes.

Adenosine triphosphate (ATP): A compound of adenosine containing three phosphoric acid groups. When this substance is split by enzyme action, energy is produced. The energy of the muscle is stored in this compound.

Aerobic: Requiring the presence of oxygen during exercise.

Afferent: Sensory neural impulses ascending toward the brain.

Agonist: A directly engaged muscular contraction in opposition to the action of another muscle.

Aikido, Aikijujutsu: A soft martial art, literally translated "The way of unified the soul." Both martial arts can be very harsh, which depends mostly on the headmaster of the school or the system.

Aikidoka: The person who practices Aikido.

Alpha motoneuron: A neuron innervating power producing, extrafusal muscle fibers.

Albumin: A simple protein group found in animal and plant tissues.

Amphiarthrodial (amphiarthrosis): Surfaces connected by fibro-cartilage, not separated by synovial membrane, and having limited motion. For example, bodies of vertebrae.

Anaerobic: During exercise the oxygen requirement can be reduced substantially or totally.

Angular momentum: The product of moment of inertia of a body about an axis of rotation and angular velocity of the body about the same axis.

Angular motion: *see* motion. (1) A motion resulting from a force that is not applied through the center of gravity of the object/body. (2) A progressive change in position of an object/body with respect to time.

Antagonist: A muscle that has an opposite effect on movers such as an agonist muscle by opposing the action or contraction of the muscle.

Antebrachium (Latin): The forearm.

Aponeurosis: A flat fibrous sheet of connective tissue that serves to attach muscle to bone or other tissues.

Aspera: *see* linea aspera. A longitudinal ridge on posterior surface of middle third of the femur.

Astrocyte: A star-shaped neuroglial cell.

Attacker: Person who initiates and executes an attack against another person.

Axilla (Latin): The armpit.

Axis/fulcrum: A fixed point or center of rotation of a lever arm.

Axon: A long and slender part of the nerve cell that is part of the main cell body, which can be connected to another nerve tissue.

Axon hillock: A thicker part of the axon where it joins the soma. At this site of the soma, action potential generates.

Balance (body): The ability to maintain a stable and controlled upright body position.

Basal metabolic rate (BMR): The minimal level of energy required of a person to sustain basic metabolic rate for life. It is required to sustain body's vital functions in an awake state, during which the person is completely at rest in supine position, consumes minimal oxygen, and does not eat or drink any liquid.

Body turnings (*Tai-sabaki* in Japanese): A specific body turning executed by legs of the martial artist. These turnings are specific to almost all different martial arts. It is used to maintain the body position but outside of the attack range.

Body-type (somatotype): The characteristic physical appearance and shape of an individual. There are known three major body types: Endomorph which is characterized by a rounded body shape with more adipose tissue. Mesomorph is characterized to be a muscular-type individual. Ectomorph is characterized to be a slender-type individual.

Brachial plexus: Network of lower cervical and upper dorsal spinal nerves supplying the arm, forearm, and hand.

Brain stem: The lowest portion of the brain which is connected to the vertebral column. The upper and inner portion of the brain stem consists of the mesencephalon (mid-brain), pons, and medulla oblongata. It performs motor, sensory, and reflex functions. The 12 pairs of cranial nerves from the brain arise mostly from the brain stem.

Break-fall (*Ukemi* in Japanese): A special technique of falling down on the fighting mats (*Tatami* in Japanese) in order to minimize the shock with the ground. The techniques consist of rolling, salting, and more importantly hitting with the extended arm including the palm on the Tatami.

Bursa: A fibrous sac between certain tendons and the bones beneath them, lined with a synovial membrane that secretes synovial fluid. The bursa acts as a small cushion that allows tendons to slide over the bones.

Calcium and Ca^{2+} ion: Calcium is one of the most important mineral along with potassium, sodium, magnesium, iron, and others. Calcium is needed for strong bones.

Calcium plays an important metabolic role as a cofactor to ATP, which is instrumental in the release of energy for muscular contraction. The body requires calcium ion (Ca^{2+}) for the transmission of nerve impulses, muscle contraction, and other vital body processes.

Capsule: A sheath or continuous enclosure around an organ or structure.

Cardiovascular (reflex) center: The cardiovascular center is a part of the human brain responsible for the regulation of the rate at which the heart beats. It is located in the medulla oblongata. Normally, the heart beats without nervous control, but in some cases (e.g., exercise, trauma to the body), the cardiovascular center is responsible for altering the rate at which the heart beats. The sympathetic fibers speeds up the heart rate, the vagus nerve slows down the heart rate.

Carbohydrate: Any of a group of organic compounds. The most important are: sugar, starch, cellulose. According to molecular structure they can be classified as; di-, tri-, poly-, and heterosaccharides. Carbohydrates constitute the main source of energy for all body functions.

Carpal tunnel: A narrow passageway between the carpal bones and the flexor retinaculum on the palm. The carpal tunnel associated with the median nerve that comes from the wrist to the palm.

Cartesian (rectangular) coordinate system: A system works in 2-D axes (x, y) or 3-D axes (x, y, z), in which a point is located between these reference lines.

Cartilage: A nonvascular supporting connective tissue composed of various cells and fibers, found mostly in joints.

Cell: The fundamental unit of living tissue. Each cell consists of a nucleus, cytoplasm, and organelles surrounded by a cytoplasmic membrane.

Central nervous system (CNS): One of the two main divisions of the nervous system of the body, consisting of the brain and the spinal cord.

Centrifugal force: A force that is directed outward, away from a central point or axis.

Centripetal (radial) acceleration: An object which accelerates toward the axis of rotation, due to a change in its direction when the object is moving along a curved path.

Centripetal (radial) force: Force acting toward the center of rotation. It is responsible for keeping the object moving on the curved path.

Cerebellum: Part of the brain located in the posterior cranial fossa behind the brain stem. Its functions are concerned with coordinating voluntary muscular activity.

Cerebrum: The largest and uppermost part of the brain, divided by the longitudinal fissure into the left and the right cerebral hemispheres.

Circumduction: A circular movement of a limb or the eye. The limb circumscribes a conical movement with the apex of which is on the joint of the limb and the base of which is described as a large circle.

Coefficient of friction: A special index number indicating the molecular interaction of two surfaces that could indicate a sliding movement with one another or simply stick together. The index number of "0" indicates a perfect smooth and frictionless surface. In this case the two surfaces could slide easily on each other. The static friction of an index number usually is higher than number "1." The slippery surfaces would indicate a coefficient of kinetic friction.

Coefficient of restitution: Index of elasticity of an object reflecting the ability of the object to return (maintain) to its original shape once deformed. It is measured by the ratio of impulse of rebound to the impulse of impact.

Cofactor: A nonprotein portion of an enzyme that is involved in a chemical reaction.

Collagen: A substance consisting of bundles of tiny reticular fibrils, which combine to form the white, glossy inelastic fibers of the tendons, the ligaments and the fascia.

Collision: A hard interaction such as a crash of immovable or movable two bodies. There are two kinds of collision. (1) Elastic collision in which the total kinetic energy of the conversion remain unchanged after the collision, the body or bodies remain intact or regain their original shape. (2) Inelastic collision in which the total kinetic energy of conversion is decreased by the collision.

Concentration gradient: A difference in concentration from one region to another. Ionic concentration gradients across the neuron membrane help determine the membrane potential.

Concentric contraction: Any movement involving a shortening of muscle fiber while developing tension, for example, a flexion movement of the biceps muscle. It is an isotonic or positive contraction.

Concentric force (direct force): A force which has its line of action passing through the center of gravity of the body on which it acts.

Conditioned reflex: A response which presumably is learned. A conditioned behavior is obtained by a stimulus. A conditioned reflex is one which has become more frequent after being reinforced.

Conductivity: The reciprocal of resistivity. It is defined as the current density divided by the electric field strength. Conductivity is measured in Siemens per meter.

Condyle: A rounded protuberance at the end of a bone forming an articulation.

Conservation of energy: The principle that energy cannot be created or destroyed, although it can be changed from one form to another.

Contractile element: A muscle fiber that has the ability to contract, or shorten.

Contractility: The ability of an object to contract.

Contraction: The movement of contraction or shortening.

Coronoid process: A projection, outgrowth, bone or tissue on the head of the ulna bone.

Cranium: The portion of the skull that encloses the brain. It is a rounded bony structure that include; the frontal, occipital, sphenoid and ethmoid bones, and the paired temporal and parietal bones.

Creatine phosphate or phosphocreatine (PCr): An energy-rich compound that plays a critical role in providing energy for muscle action from ADP to ATP.

Curvilinear: A curved path.

Cytoplasm: The totality of the cell substance excluding the nucleus.

Deceleration: Decrease in an object's velocity per unit time. Slowing down process from an acceleration.

Defender: Person who will be thrown, taken down, subdued. However, when the defender managed to defend him and counter attack, then the defender became an attacker.

Dendrite(s): A branched protoplasmic (organic or inorganic substances) of a neuron that conducts impulses to the cell body (nucleus). They form synaptic connections with other neurons.

Depolarization: The process of neutralization of the polarity.

Depression: (1) A hollow region of a body. (2) Movement of the shoulder region or another body part downward.

Diaphysis: The shaft of a long bone, consisting of a tube of compact bone enclosing the medullary cavity.

Diarthrodial: Pertains to a movable articulation such as diarthrosis articulation; an articulation in which opposing bones move freely; a hinge joint.

Diencephalon: Called also interbrain. It consists of the hypothalamus, thalamus, metathalamus, and epithalamus.

Direct force: *see* concentric force.

Displacement: A direct line between the starting point of the body/object and the end point of that body/object; includes the magnitude and direction of the positions (initial and final). The angular displacement includes an angle between the initial and final positions of a rotating object or body.

Distal insertion (attachment): A point of attachment of a muscle to a bone which usually moves during an isotonic or isokinetic muscle action. The insertion is usually distal to the origin.

Distance: Space between two points or objects.

Dorsal root (spinal) nerves: They are 12 in number on each side (anterior and posterior rami). The first appears between the first and second dorsal vertebrae, and the twelfth between the last dorsal and first lumbar. These nerves are of small size, but can vary slightly from the second to the last 12. These nerves serve as the major sensory input for the spinal cord.

Dorsiflexion: To bend or flex backward as in the upward bending of the fingers, wrist, foot, or toes.

Downward rotation: The downward rotation is related to movements of the scapula. The outer edge of the scapula from an outward position rotates into an inward position, being as normally as the scapula is in neutral position.

Downward tilt: The turning of the scapula on its frontal–horizontal axis. The scapula posterior surface is downward from a position of the upward tilt.

Drag force: *see* force of drag.

Dynamic equilibrium (balance): The position of an object or person who can maintain a stable balance in motion. The position when an object or a person is perfectly immovable it is said to have a static equilibrium.

Dynamics: A branch of mechanics related to the study of kinematics and kinetics.

Eccentric contraction: Muscle action producing lengthening its muscle fibers while developing tension, as in biceps muscle during a movement of arm extension; it is a negative contraction.

Eccentric force: A force that does not act through the center of gravity or through a point at which the body is fixed (such as the axis of rotation). Such a force produces translation and rotation. Its rotatory effect is known as torque.

Ectomorph: *see* body type.

Efferent: Directed outward from the center of the body, as the nervous signals directed from the CNS to the executor organs.

Elastin: An extracellular connective tissue protein that is the principal component of elastic fibers.

Elastic collision: *see* collision.

Elasticity: Property of a body or a muscle in which the muscle will recoil or regain its original shape after being stretched, deformed.

Electrolytes: A compound that, when melted or dissolved in water or other solvents, dissociates into ions and is able to conduct an electric current. The most important electrolytes are sodium, potassium, and calcium. They are fundamentally important for sustaining life. Calcium and potassium are necessary to contract and relax the muscle, sodium is essential to maintain fluid balance.

Elevation: A movement of a body part which is moving in an upward direction.

Eminence: A bulge or projection, usually rounded in shape and is on the surface of an organ or muscle, for example, hypothenar eminence.

Endomorph: A body type that is characterized by a rounded body shape, having excessive fat in and around the lower part of the body especially around the abdomen area.

Endomysium: A connective tissue that surrounds every muscle tissue.

Endoplasmic reticulum (ER): An extensive network of membrane-enclosed tubules in the cytoplasm of the cell. ER can be studded with submicroscopic bodies called ribosomes. The ER is the site of protein synthesis in a cell.

Energy: The capacity to do work or perform activity.

Epicondyle: A projection on the surface of a bone above its condyle, for example, such as the humerus medial and lateral epicondyle.

Epimysium: A fibrous outermost sheath that enfolds a skeletal muscle, consists of reticular, collagenous and elastic fibers, connective tissue cells, and fat cell.

Epiphysis: The head of a long bone that is separated from the shaft of the bone by the epiphysial plate until the bone stops growing, the plate is obliterated and the shaft with the head becomes united.

Epitrochlea: The medial epicondyle at the distal end of the humerus.

Equilibrium: *see* dynamic equilibrium (balance).

Eukaryotic cell: An organism having cells that contain a true nucleus.

Eversion/inversion: Movement of a body part outward, such as lateral movement of the sole of the foot. Inversion is the medial movement of the sole of the foot.

Excitability: The ability to receive and respond to a stimulus.

Extensibility: The ability to stretch a material, a muscle beyond its resting length.

Fascia: A fibrous connective tissue of the body that may be separated from other specifically organized structures such as tendons, aponeuroses, and ligaments. Fascia has different thickness and density and fat content, all depends on the area where the fascia is located.

Fasciculus: A small bundle of muscle, tendon, or nerve fibers. Fasciculus has different shapes such as penniform, bipenniform, multipenniform, and radiated.

Filament: A thread-like muscular protein such as myosin a thick filament and actin a thin muscular protein.

Finalization throw (*Kake* in Japanese): The execution of a throwing technique in judo, jujutsu, and Aikido. In Aikido, the throwing execution is named *Nage* in Japanese.

Flexibility: The ability to move a joint through its complete range of motion and even beyond.

Foramen: An opening or orifice in a membranous structure or bone, as the carotid foramen or foramen magnum which is a passage in the occipital bone through which the spinal cord enters the spinal column.

Force: An action, push, pull or twist that causes a change in the state of motion of an object, the product of the mass of an object and its linear acceleration. Force also can be described, when energy applied in such a way that it initiates motion, changes the speed or direction of motion, or alters the size or shape of an object.

Force arm: *see* moment arm or lever arm. The shortest perpendicular distance between a force's line of action and an axis of rotation. The lever arm has two parts beside the axis of rotation or fulcrum. (1) Force arm in human mechanics is represented by the muscle force. (2) Resistance arm which is represented by the weight of that part of the lever arm and also the force of gravity.

Force couple: Two equal but oppositely directed rotational forces acting simultaneously on opposite directions of an axis of rotation.

Force of drag: Component of a resistive fluid force acting in the same direction as the fluid flow past the object, resulting in a reduction in the object's velocity.

Force radial (centripetal force): *see* centripetal (radial) force.

Force (external/internal): Force outside of a system. Internal force that is generated internal of a system, for example, muscle force that cannot be shown on a free body diagram (FBD).

Free body diagram: Stick figure drawing of a system, showing all the external forces action on that system.

Frequency of excitation: Number of times an excitation/stimulus occurs in a given period for a muscle fiber that can respond with an impulse.

Friction: A resisting force to a motion between two surfaces in contact with each other. There are two kinds of friction force. (1) Static friction, when the objects stick together. (2) Kinetic friction, when one of the surfaces of an object can slide over the other one or both objects can slide one on other.

Frontal (coronal) plane: A plane that divides the body into anterior and posterior parts.

Gamma motoneuron: Any of the motor nerve fibers that transmit impulses from the central nervous system (CNS) to the intrafusal fibers of the muscle spindle.

Ganglion: One of the nerve cells, chiefly collected in groups outside the CNS.

Glenoid cavity or glenoid fossa: A shallow rounded depression in the scapula into which the head of the humerus is inserted and connected with different ligaments such as glenohumeral (middle, superior, and inferior), humeral transverse, and so on.

Glenoid labrum: A fibrous cartilage around the glenoid cavity, giving extra stability to the glenohumeral joint.

Glycogen: A polysaccharide consisting of a highly branched polymer of glucose occurring in animal tissues, especially in muscle cells and liver. It is a major supply of carbohydrate energy in animal cells.

Glycolitic: Refers to anaerobic type of activity.

Glycoprotein: A carbohydrate linked covalently to a protein. Covalent bonds are formed by sharing of valence electrons rather than by transfer.

Glycosaminoglycan: A member of a group of polysaccharides that contain glucosamine. Provides lubrication for the joints and forms part of the matrix of cartilage.

Golgi apparatus: (Camillo Golgi, Italian anatomist), one of many small membranous structures found in most cells, composed of various elements associated with the formation of carbohydrate side chains of glycoproteins, polysaccharides, and other substances.

Golgi tendon organ: A sensory nerve ending that is sensitive to both tension and extreme passive stretch of a skeletal muscle.

Graded potential: A temporary change (localized) depolarization or hyperpolarization in the membrane potential.

Graphical (geometrical) method: In this method, the vectors are added by a graphical way, by using ruler, pen, protractor.

Gravity: The attraction between the Earth and an object with a force proportional to the product of their masses and inversely proportional to the squared distance between them.

Gravitational potential energy: This energy is stored within an object due to its height above the surface of the Earth. The amount of energy used to lift the object against gravity is then stored as gravitational potential energy within the object.

Ground reaction force (GRF): The resultant reaction force, equal and opposite to the applied force, of the supporting surface. The resultant force direction is also equal to the force direction which has been applied toward the ground.

Hakama: A very large and long skirt usually black in color which is used for three purposes. (1) To cover the foot movements. (2) It is a customary Japanese outfit. (3) In martial art of Aikido the Hakama is used by a black belt Aikidoka.

Helix: A coil-like structure.

Hillock: The cone-shaped hillock covers the axon of the cell.

Homeostasis: A relative constancy in the internal environment of the body that is sustained by different mechanisms, such as the heart beat, blood pressure, body temperature, respiration, electrolytic balance, and glandular secretion.

Horse power: A British unit of power, one horsepower is equal to the work done at a rate of 550 foot pound per second. It is equivalent to

745.7 W. The German unit of horse power is the Pferde Störke (PS), pferde = horse, störke = power, is 75 kgf m/s or 735.4 W.

Hyaline cartilage: It is a smooth, shiny cartilage which covers the articular surfaces of bones.

Hydrocarbon: Chemical compound that contains only carbon and hydrogen. The most known hydrocarbon compounds are alkanes, alkenes, alkynes.

Hydrolysis: The splitting of a water molecule into H^+ and OH^- through interaction with another species solution.

Hydrostatic(s): The study of forces and pressures of liquids at rest.

Hyperpolarization: A change in the potential difference of the cell membrane by an increase in the value of the negative membrane potential, for example, from a –70 mV it my change to –80 mV value.

Hypertrophy: Increase in size or mass of an organ or body.

Hypothalamus: A portion of the diencephalon of the brain, forming the floor and part of the lateral wall of the third ventricle. It activates and controls the peripheral autonomic nervous system (ANS), and many somatic functions, as body temperature, sleep, and appetite.

Hypothenar (eminence): A bulge or projection of muscles on the medial side of the palm. This portion serves four muscles: Musculus palmaris brevis, flexor digiti minimi brevis, abductor digiti minimi, and opponens digity minimi.

H-zone: A sarcomere is the basic functional unit of a myofibril. Within a sarcomer there are different functional units with different zones and bands. The H-zone is the central portion of the A band, and contains only myosin filaments.

I-band: Indicates the region of the sarcomere where there are only actin filaments.

Impact force: It is specific for forces over a short period of time. Its unit is $kg \cdot m/s^2$ or N.

Impulse or (impulsive force): It is a force multiplied by time duration and is similar to momentum or better said it changes momentum. Its unit is: $J = kg \cdot m/s$ or $(N \cdot s)$.

Impulse–momentum relationship: States that the impulse is equal to the change in momentum of an object. $J = m\,\Delta v\ (v_f - v_i)$.

Inelastic collision: *see* collision.

Inertia: A tendency of a body to remain in its state of rest or in motion in a straight line, until acted upon by an outside force.

Inertial frame of reference: A reference frame with zero acceleration, the speed and direction of motion are unchanged.

Infraspinatus: A muscle beneath the scapular spine.

Inorganic phosphate (P_i): The P_i and ADP go hand in hand during mitochondrial transport. Both P_i and ADP must enter the mitochondrial matrix and at the same time ATP must leave the mitochondrion. P_i also has an important role in the regulation of the oxidative phosphorylation.

Inorganic substance: Pertaining to a chemical compounds that do not contain carbon as a principal element (except carbonates, cyanides, and cyanates).

Interneurons: Neurons receiving information from and transmitting it to other neurons. Interneurons are not sensory and motor neurons pertain to the CNS in which they reside.

Interoceptor: Any sensory nerve ending located in cells in the viscera that responds to stimuli originating from within the body regarding the function of the internal organs, as digestion, excretion, and blood pressure.

Interossei: Situated between bones, as muscles, ligaments, or vessels; specific muscles of the hands and feet.

Intertubular: Between or among tubules.

Intrafusal fibers: A specialized muscle fiber within a muscle spindle that receives motor innervations from gamma motor neurons.

Ion: An atom, groups of atoms or molecules in which the total number of electrons is not equal to the total number of protons. The atom or groups of atoms has acquired an electric charge through the gain or loss of an electron or electrons.

Isokinetic: Muscular contraction that occurs at a constant velocity over the full range of motion.

Isometric: The muscle maintains the same length during a muscular tension.

Isotonic or dynamic: A form of muscular activity in which the muscle contracts and causes movements. Usually the movement is under aerobic activity.

Joint or articulation: Connection of two closest bones in the human body. They share functionality.

Joule: It is an SI unit of all forms of energy (mechanical, thermal, and electrical), defined as the energy equivalent to the work performed as the point of application of a force of 1 N moves through 1 m distance in the direction of the force.

Judo, jujutsu: A Japanese fighting system, where the defender not necessarily must use an excessive force in order to defend himself. Judo literally translated the "Way of softness" and the jujutsu translated the "Soft art."

Judoka, jujutsuka: The person who practices judo or jujutsu.

***Kake* (in Japanese) throwing:** In judo terminology the *kake* means throwing, however, the correct Japanese word for throwing is *Nage*. *Nage* also means the thrower or the attacker.

Karateka: The person who practices the art of karate.

ki (chi or qi): It is a word used from the Eastern society particularly the Japanese, Chinese, Korean, and so on. Translated it means the "internal energy, energy of the soul or vital energy" of a person.

Kinematic chain or kinematic couple: In human body system connection of two body parts which transmit forces. In this last sentence there is a controversy between some biomechanist. In modern biomechanics the word kinematic means describing motion of an object and its velocity related to its distance. However, if we use the word of "kinetic chain" which is correct, one could refer to the force transmission from one segment to another.

Kinematics: *see* kinematic chain.

Kinesthesis: Information gathered from a combination of senses through muscle spindles, Golgi tendon organs, joint receptors, semicircular canals of the ear, gives the performer a feeling of limb position in space.

Kinetic chain: *see* kinematic chain.

Kinetic energy: Capacity of an object to do work by virtue of its linear or angular motion.

Kinetic link principle: The principle says that body segments generate high end-point velocity by accelerating and decelerating adjacent links, using internal and external muscle torques applied to the body segments in a sequential manner from proximal to distal, from massive to least massive, and from fixed to free. In other words the momentum, energy, velocity can be accelerated from a massive body to a lighter body if the lighter body has a high moment of inertia.

***Kokyu-ryoku*:** A specific exercise in Aikido where the grabbed arms can be easily liberated.

Krause's membrane: It is synonymous to Z-line or Z-disk.

Kyusho: Represents pressure on the human body-sensitive points. These points enclose receptive sensory nerves, major arteries and veins, when those points are pressed or hit, the body of the hit person could collapse due to physiological adverse reaction (pain, dizziness, sock, and even death).

Lever arm: *see* moment arm, force arm.

Liberation of Ca^{2+} ion: By the result of action potential, sarcoplasmic reticulum releases Ca^{2+}.

Ligament: A white, shiny, flexible band of fibrous tissue, which is used to connect bony component to another bony component.

Ligamentum flavum: Any of the series of ligaments of yellow elastic tissue connecting the laminae of adjacent vertebrae from the axis to the sacrum.

Linea alba: The portion of the anterior abdominal aponeurosis in the middle line of the abdomen.

Linea aspera: The posterior crest of the thigh bone, extending proximally into three ridges to which are attached various muscles, including the gluteus maximus, pectineus, and iliacus.

Lipid: Any of a class of greasy organic substances insoluble in water but soluble in alcohol, ether, and other solvents.

Limiting friction (force): *see* static friction. For two dry surfaces the limiting friction force is a product of the normal reaction force and the coefficient of limiting friction.

Lipid-soluble molecules: Substances which are insoluble in water. Some examples are butter, vegetable oil, waxes, cholesterol, and others.

Lumbricals: Any of the four small muscles of the palm of the hand that arise from tendons of the flexor digitorum profundus, are inserted at the base of the digit to which the tendon passes.

Lymphatic: Related to lymphoid tissue or lymphocytes.

Lymphoid cell: Any of the cells responsible for the production of immunity mediated by cells or antibodies that includes lymphocytes, lymphoblasts, and plasma cells.

Magnitude: The amount or size of an acting force that is being applied. Magnitude includes temperature, mass, distance, volume, brightness, force, and so on.

Mass: The measure of the amount of matter that comprises an object. Mass is measured in kilograms (kg).

Mastoid process: The conical projection of the caudal, posterior portion of the temporal bone, including the sternocleidomastoideus and splenius capitis muscles.

M-line or (disc): Thin dark line in the midsection of the H-zone of a striated muscle fiber, is also called M-band.

Matrix: (1) An intercellular substance. (2) A basic substance from which a specific organ or a tissue develops.

Mechanical advantage: The ratio of the force arm (FA) to the resistance arm (RA) in a lever (torque) system. To find out the mechanical advantage the equation is FA/RA. Where if the FA is longer than the RA arm, then there is a mechanical advantage.

Mechanical axis: The mechanical axis of a bone is a straight line that connects the midpoint of a joint at one end (distal) with the midpoint of a joint at the other end (proximal).

Membrane potential: The voltage across a cell membrane; represented by the symbol mV.

Meniscus: Either of two crescent-shaped lamellae of fibrous cartilage that border and partly cover the articulating surfaces of the tibia and femur at the knee. Also known as semilunar cartilage.

Mesenchyme: A network of tissue derived from the embryonic mesoderm. It consists of stellate cells embedded in gelatinous matrix.

Mesomorph: *see* body type.

Mitochondrion: Any of small rod-like, various round shape or cellular organelles of most eukaryotes that are found outside the nucleus, produce energy for the cell through cellular respiration, and are rich in fats, proteins, and enzymes.

Mobility: A motor quality of the joint. The ability of two body segments to move easily between their range of motion. The joint can move sometimes over its RoM.

Module of elasticity: The ratio of stress to strain for a body.

Moment (torque): Angular or twisting action produced by a force that acts eccentric to the axis of rotation named also as torque.

Moment arm: The perpendicular distance from the axis of rotation to the line of action of a force. Also called force arm, resistance force arm.

Moment of inertia: (1) The sum of the products of the point masses and the distances of the point masses from the axis of rotation. (2) The resistance of an object to a change in its angular rotation.

Momentum: The amount of motion possessed by a moving object.

Motoneuron (motor neuron): A nerve cell that transmit nerve impulses from the brain or from the spinal cord to muscles or to glandular tissues. According to location, there are peripheral and upper motoneurons.

Motion: Progressive change in position of a body with respect to time.

Motor unit: One single alpha motor neuron and all of the muscle fibers it innervates. Each motor unit supplies from four to hundreds of muscle fibers.

Motor end plate: The terminal ramification of a motor axon on a muscle fiber.

Movement: A change in position of a whole body, body part or the center of mass in relation to a reference point.

Movement type (form): A type of physical activity such as limbering the body, practicing sport, game or different types of exercise. These forms are not practiced under different rules.

Multilink system function: Relating to the appendicular anatomy (bones, joints, and muscles). The multilink system functions as one entity, for example, throwing a ball, the upper and forearm bones and their muscles with the elbow joint works together as a multilink system.

Muscle attachment: The physical connection to be attached or fixed one body or body part to another.

Muscle density: Refers to the amount of mass in a given volume.

Muscle fatigue: A decreased capacity to perform a maximum voluntary exercise or a series repetitive muscular activity. Muscle fatigue may result from depletion of phosphocreatine or glycogen and the accumulation of pyruvic and lactic acid.

Muscle fiber: A multinucleated muscle cell which contains the contractile elements of the muscle and those are the actin and myosin filaments in a sarcomere.

Muscle insertion: The place of attachment, as of a muscle to the bone it moves. The attachment can be proximal or distal.

Muscle power: The ability of a muscle or muscle group to exert a maximum force in a shortest period of time. This ability named in Japanese as *Kime* or focus, which means to execute a maximum strike or blow in a shortest time. This is also related to impulse in karate, where the time of delivery should be as short as possible.

Muscle spindle mechanism or stretch receptor: A sensory receptor within skeletal muscles that senses muscle length; provides

sensory information to neurons in the spinal cord via group afferent fibers.

Muscle fiber type: There are three muscle types: Red Slow-twitch oxidative or "Type I fibers" (SO), they work with plenty of oxygen supply. White Fast-twitch glycolitic, called "Type IIB fibers" (FG), they contract rapidly, but tire also rapidly because of the less oxygen supply due to short glycogen reserves. Intermediate Fast-twitch oxidative glycolitic or "Type IIA" fibers (FOG), they are between red and white fibers.

Muscular tonus: The normal state of balanced tension in a muscle tissue. Partial contraction and relaxation of neighboring fiber of a group of muscles hold the organ or the part of the body in neutral, functional position without fatigue.

Myelin sheath: A layer of myelin surrounding some nerve fibers.

Myofibril: One of the longitudinal parallel of the contractile elements of a muscle cell that are composed of actin and myosin.

Myoglobin: A red protein pigment containing iron in muscles that is similar to hemoglobin.

Myosin: A fibrous globulin of muscle that can split ATP and that reacts with actin to form actomyosin.

Myotatic or stretch reflex: A spinal reflex involving reflex contraction of a muscle in response to stretching.

Nerve cell, neuron: One of the cells that comprise the nervous tissue, that have the property of transmitting and receiving nervous impulses.

Neuroglia: One of the two main kinds of cells comprising of the nervous system. It performs the less specialized functions of the nerve network.

Neurocranium: The portion of the skull that encloses and protects the brain.

Neuromuscular junction: The junction of an efferent nerve fiber and the muscle fiber plasma membrane also called myoneural junction.

Neuromuscular synapse: Neuromuscular pertaining to the nerves and muscles. Synapse pertains to the place where a nervous impulse (particularly an action potential) passes from one neuron to another. The transmission of nerve impulses is done between synaptic knobs or clefts and is transmitted from the presynaptic to the postsynaptic muscle membrane.

Neurotransmitter: Anyone of numerous chemicals that modify or result in the transmission of nerve impulses between synapses.

Neutralizer: (1) A muscle that contracts in order to counteract, or neutralize, an undesired action of another contracting muscle. (2) A neutral substance that is neither positively nor negatively charged.

Newton: The SI unit of force, defined as the force that provides a mass of 1 kg with an acceleration of 1 m/s^2. The symbol is N.

Newton's law of impact: States that if two bodies move toward each other along the same straight line, the difference between their velocities immediately after impact has a constant relationship with the difference between their velocities at the moment of impact.

Newton's laws of motion: Sir Isaac Newton (1642–1727) formulated several laws that is still recognized today; the law of gravitation, law of acceleration, law of action–reaction, law of inertia, law of cooling, law of impact, law of fluid friction.

Normal force or reaction force: The normal force acting perpendicular to the supporting surface. The reaction force resultant is equal and opposite to the applied force of the supporting surface.

Nucleic acid: A polymer consisting of many nucleotide monomers.

Nuchal line: There are three ridges on the back side of the skull. There are the superior, middle, and inferior nuchal lines. The most protuberant is the superior nuchal line which is also palpable.

Off-balancing (*Kuzushi* in Japanese): The physical maneuver which makes the opponent to lose his balance.

Oligodendrocyte: A neuroglial cell resembling an astrocyte but smaller with few and slender processes having few branches.

Organelle: Any one of various particles of living substance bound within most cells, as the mitochondria, the centrioles, and the lysosomes.

Organic: Any chemical compound containing carbon.

Osmosis: The movement of the pure solvent, as water, through a semipermeable membrane from a solution that has a lower solute concentration to one that has a higher solute concentration.

Osteoblast: A cell that originates in the embryonic mesenchyme and, during the early development of the skeleton, differentiates from a fibroblast to function in the formation of bone tissue. When osteoblast matures, it develops and becomes osteocytes.

Osteocyte: A bone cell; a mature osteoblast embedded in the bone matrix.

Osteogenesis: The total development (ossification) of the bone tissue.

Osteoporosis: A disorder characterized by a decreased bone mass of a bone.

Oxidation: A reaction in which a substrate loses electrons.

Oxidative phosphorylation: The synthesis of ATP from ADP and P_i for which energy is obtained by electron transport system.

Parallelogram method: The geometric representation of two or more vectors. The resultant vector is given by the direction and length of the diagonal vector.

Parallel axis theorem: The relationship between the moment of inertia about an axis through a segment's center of gravity (CoG) and about any other parallel axes.

Parasympathetic: The system is pertaining to the craniosacral division of the autonomic nervous system (ANS), consisting of the oculomotor, facial, vagus, and pelvic nerves. The parasympathetic division involves the conservation and slowing down of the vital processes; for example, slowing down the heart beat, and so on.

Passive movement: The moving of the body parts by an outside force without voluntary action or resistance by the individual.

Pedicle: A bony process.

Periosteum: A fibrous vascular membrane covering the bones, except at their extremities.

Peripheral nervous system (PNS): The motor and sensory nerves and ganglia outside the brain and spinal cord. The afferent peripheral nerves transmitting information to the CNS and efferent peripheral nerves carrying impulses from the brain.

Peritoneum: A widespread serous membrane that covers the entire abdominal wall of the body and it is connected over the contained viscera.

Perimysium: The connective tissue sheath that surrounds a bundle of muscle fibers.

pH: Named hydrogen potential. A scale representing the acidity and alkalinity of a solution in which a value of 7 is neutral, below 7 is acid, and above 7 is alkaline. The pH value indicates the relative concentration of the hydrogen ion in the solution. Comparison is made with a standard solution.

Phosphocreatine: *see* creatine phosphate (PCr).

Phosphorylation: Addition of one or more phosphate groups to a molecule.

Planes (body planes): An imaginary 2-D surfaces which divides the body in different planes, usually in two parts; the frontal (coronal) plane divides the body in anterior and posterior parts, the transverse (horizontal) plane divides the body in upper and lower parts, the sagittal (mostly middle sagittal) divides the body in right or left parts.

Platysma: A broad and thin layer of muscle that is situated on each side of the neck immediately under the superficial fascia belonging to the group of facial muscles.

Pleura: A thin serous membrane enclosing the lung, it is a single layer.

Plexus: A network of intersecting nerves and blood vessels or of lymphatic vessels. The body contains several plexuses; brachial, cardiac, cervical, and solar plexus.

Point system in judo: In judo tournaments to decide who is the winner there is a point system which is used: (1) A full point or 10 auxiliary points (*Ippon*) (immediate winning), (2) 7 auxiliary points (*Wazaari*), (3) 5 auxiliary points (*Yuko*), and (4) 3 auxiliary points (*Koka*).

Polar coordinate: In this system the point in space (P) is determined by the length of the vector from the origin (0) to the point in space, and the angle between the vector line and the right horizontal axis (usually the abscissa line).

Polarity: (1) The difference between the two parts of the neuron membrane has distinctive and different electric charge such as positive and negative. (2) The distinction between the north and south poles determined by a magnet.

Polarized: An unstimulated neuron membrane is said to be in a polarized state.

Polysaccharides: A carbohydrate that can be decomposed by hydrolysis into two or more molecules of monosaccharides.

Positioning (*Tsukuri* in Japanese): In judo before throwing an opponent there are three unseparable actions: (1) Off-balancing (*Kuzushi*), (2) positioning (*Tsukuri*), and (3) throwing (*Kake* or *Nage*). The second one the positioning is executed favorable for the attacker (position himself closer to the opponent, by this way the throwing will be successful).

Postsynaptic membrane: A site of the cell membrane point where the cell conducts impulses (excitatory or inhibitory) away from a synapse. Compare with *presynaptic membrane* where the cell receives information through a synapse.

Potassium, K^+ ion: An alkali metal element, the seventh most abundant in the Earth's crust. Potassium is important in glycogen formation, protein synthesis, and in the correction of imbalances of acid–base metabolism.

Potential energy: The ability of a body to do work by virtue of its linear or angular motion; measured in joules.

Power: (1) The product of force and velocity. (2) The amount of work done per unit time.

Power stroke (sliding-filament theory): During muscular contraction in the sarcomeres the two major sliding muscular filaments (thin actin and thick myosin) are pulled together. The thin filaments are pulled over the thick filaments in each sarcomere. During this contraction is triggered by a nerve impulse that will cause a power stroke or action potential.

Presynaptic membrane: *see* postsynaptic membrane.

Prokaryotic cells: An organism that does not contain a true nucleus surrounded by a nuclear membrane, characteristic of lower forms of life, as bacteria, viruses, and blue or green algae.

Pronator (pronation): A position, one in which the ventral surface of the body or body part faces downward. For example, the forearm with the palm oriented downward.

Proprioceptor: Any sensory nerve ending, as those located in muscles, tendons, joints, and the vestibular apparatus, that responds to stimuli originating from within the body regarding movement and spatial orientation.

Protein: Any complex naturally occurring organic nitrogenous compounds. Each is composed of large combinations of amino acids containing the elements of carbon, hydrogen, nitrogen, oxygen some sulfur and, phosphorus, iodine, iron, and so on. The amino acids are the building elements of the proteins.

Protraction: A forward movement of a body part in a transverse plane, such as the forward projection of a mandible when the jaw is jutted out, or as in the shoulder girdle.

Protrusion: To project just outward.

Protuberance: Bulging beyond the surrounding area.

Pubic symphisis: The slightly movable interpubic joint of the pelvis, consisting of two pubic bones separated by a disk of fibrous cartilage and connected by two ligaments.

Quadrants: A circle divided equally into four parts in which each part represents a quadrant.

Rachet movement: The ratchet movement is the contraction of the muscle.

Radial acceleration or centripetal acceleration: The acceleration of an object, acting toward the axis of rotation.

Ramus: A small, branch like structure extending from a larger one or dividing into two or more parts, as a branch or artery or nerve.

Range of motion (RoM): The angular displacement through two joined segments move.

Rectilinear motion: Linear movement on a straight line.

Reflex: The involuntary movement of an organ or part of the body in response to a particular stimulus.

Refractory period: The interval following the excitation of a neuron or the contraction of a muscle during which repolarization of the cell membrane occurs.

Relaxation: A reducing of tension, as when a muscle relaxes between contractions.

Reticular: A tissue or surface; having a netlike pattern or structure of veins.

Repolarization: Restoration of the difference in electrical charge between the inside and outside of the membrane of a muscle fiber following depolarization.

Resistance arm: Represents the perpendicular distance between the axis of rotation and the line of the resistance arm. Usually the resistance arm is represented by the gravity and the weight/mass of the object/body in case.

Respiratory reflex center: The medulla oblongata controls and regulates the respiratory movements related to autonomic functions.

Resting (membrane) potential: It is a membrane voltage, maintained by the cell when the neurons have a membrane potential of about –65 mV.

Resting metabolic rate: *see* basal metabolic rate (BMR).

Restoring force: A force tends to maintain the shape of a body and restores the original dimensions of a body once a deforming force is removed.

Retinaculum: A structure of fibrous tissue that retains an organ or tissue.

Right-hand (thumb) rule: A procedure for determining the direction of an angular vector. By curling the right-hand fingers in the direction of the rotation and by extending the thumb will point in the direction of the angular vector.

Rigid-body model (free-body diagram): Drawing stick figures that represents body parts can be used for representing a body in movement such as running, rolling, jumping, and so on.

Rotary motion: *see* motion.

Rotator cuff: Four supporting muscles of the shoulder joint such as subscapularis, infraspinatus, supraspinatus, and teres minor muscles pass to the shoulder capsule or across it to insert on the humerus.

Sagittal plane: The body is divided into left and right side/part.
Sambo: It is a Russian Judo. Very similar to judo, however, strangulation techniques are excluded from the sambo technical arsenal.
Sarcolemma: The thin transparent homogenous sheath enclosing a striated muscle fiber.
Sarcomere: Any of the repeating structural units of striated muscle fiber.
Sarcoplasm: The cytoplasm of the striated muscle fiber.
Sarcoplasmic reticulum: A network of tubules and sacs in skeletal muscles that aids muscle contraction and relaxation by releasing and storing calcium ions.
Scalar quantities: A quantity defined by a single magnitude, for example, mass, time, wave length, temperature, length, density, pressure, work, power, energy, speed.
Semilunar cartilage: *see* meniscus.
Sensory-motor integration: The process by which the sensory and motor system communicates and coordinates with each other.
Serous bursae: A bodily sac or pouch usually between tendon and bone. Produces or contains serous watery fluid.
Servomechanism: System in which a controller (using perhaps a thermostat) or the person itself (self-regulating) continuously monitored by the brain, the differences of the present and the desired homeostatic state.
Shaft: The principal portion of any cylindrical body, such as the diaphysis of a long bone.
Sheath: A tubular structure that surrounds an organ or any other body part, for example, sheath of rectus abdominis muscle.
Snap-punch: A punch which is executed extremely fast against a target, and when the target has been reached (contacted) the arm must be withdrawn also extremely fast. The contact is reduced to the minuscule time.
Sodium, Na^+ ion: An alkali metal element. It is one of the most important elements in the body and is involved in acid–base balance, water balance, the transmission of nerve impulses, and the contraction of muscles.
Soleal line: A tiny tuberosity line on the dorsal part of the tibia bone.
Solute: A substance dissolved in a solution.
Solution: A mixture of two or more substances dissolved in another substance.
Soma: A combining form of a body or a portion of a body. The body of a cell.

Speed: The rate of change of position with time.

Spindle: Any one of special receptor organs comprising of the neurotendinous and the neuromuscular spindles distributed throughout the body. These spindles serve as special receptor organs that detect the degree of stretch in a muscle or at the junction of a muscle with its tendon and are essential in maintaining muscle tone.

Splanchnocranium or viscerocranium: Part of the cranium which supports the structures of the face. The splanchnocranium includes many facial bones such as two maxilla, two palatin, two zygomatic, two nasal, and two other bones such as vomer and palatin.

Spurt and shunt muscle: A spurt muscle which has its origin at some distance from the joint about which it acts and its insertion is near the joint. Spurt muscles tend to be prime movers.

A shunt muscle has its proximal attachment near the joint at which it acts, and its distal attachment at some distance from the joint. The greater part of its force is directed along the bones, tending to pull joint surfaces together. Shunt muscles tend to be good stabilizers.

Stabilizer (fixator, anchor) muscles: A muscle that acts in a way to stabilize or anchor a bone in a desirable position, and by this action allowing other muscles to act from a firm base for a preferable direction.

Static activity: Static activity is strictly associated with body balance or equilibrium. In a balanced position the static activity of a body resumes only to muscular tonus activity which is a partial contraction of a muscle.

Statics: Branch of mechanics associated with systems undergoing zero movement.

Stenosis: An abnormal condition characterized by the constriction of an opening or passage way.

Strength: Ability of a muscle or muscle group to exert force against a resistance; usually measured as one maximal effort. In weight lifting the control technique for the strength is "one-repetition maximum" (1-RM), where the athlete should lift the maximal weight just once.

Stretch receptor: A receptor which detects stretching in a muscle. There are two types of receptors: (1) Golgi tendon organs between the muscle and its tendon (it is receptive to the muscle force). (2) Muscle spindle organs in the belly of the muscle. It passes information about the state of the muscles.

Style: A characteristic interpretation of a technique from an athlete and which is supposed to be very efficient.

Supinator (supination): A position of the body or body part by which the front part of the body can be seen (the body is on the dorsal part). For example, the palm is seen in the upward position.

Sympathetic: The sympathetic nervous system is part of the autonomic nervous system (ANS). The system activates many physiological needs, such as increase the heart rate, respiration, blood pressure, mobilization of the energy reserve, and others.

Symphysis: A unification of a cartilaginous joint in which adjacent bony surfaces are firmly united by fibrocartilage. Also called fibrocartilaginous joint.

Synapse: The area surrounding the contact point between two neurons or between a neuron and an effector organ, across which nerve impulses are transmitted by neurotransmitter chemicals such as acetylcholine.

Synaptic cleft: The outer space from the neuron at the synapse, where the presynaptic and postsynaptic nerve endings are and from where the nervous impulses are transmitted.

Synarthrodial: Pertain to an immovable articulation in which bones are united.

Syncytium: A multinucleate mass.

Synergy action: A muscle that acts in concert with another to increase its effect.

Synovial membrane: The inner layer of an articular capsule surrounding a freely movable joint, and it secretes a thick fluid that normally lubricates the joint.

Tangential force: A force which acts perpendicular to the radial force during angular rotation. This force can increase or diminish the velocity, but also is responsible for the angular acceleration.

***Tegatana* (in Japanese):** The knife hand of the palm consisting of the edge from the part of the hypothenar eminence.

Tendon: A white fibrous band of tissue that attaches muscle to bone.

Titin: A muscle protein found in sarcomeres. Titin filaments are the stabilizers of the myosin filaments.

Thalamus: A mass of gray matter in the diencephalon of the brain. It sends sensory impulses to the cerebral cortex.

Thenar eminence: A bulky muscle mass under the base of the thumb.

Tonus (muscle tone): The normal state of balanced tension in the body tissues, especially and including the muscle tissues. Partial or alternate contraction and relaxation of neighboring fibers of a group of muscles hold the organ or the body part in a neutral, functional position without fatigue.

Torque: *see* moment.

Thermodynamic law: Is a process that involves heat and energy changes. The law of conservation of energy is one of the thermodynamic laws.

Throwing: *see kake.*

Transduction: Changing the energy from one form to another form of energy.

Translation (translatory motion): It is a linear form of motion in which all parts of a body travel exactly the same distance, in the same direction, at the same time.

Transverse plane (horizontal plane): A plane that divides the body into superior and inferior halves.

Trigonometric method: The method solves vector components when the horizontal and vertical components are used in relationship of a right triangle.

Thyroid cartilage: The largest cartilage of the larynx, consisting of two laminae fused at an acute angle in the middle line of the neck to form the Adam's apple.

Tropomyosin: A long molecule that lies parallel to an actin molecule.

Troponin: A molecule which blocks a site from cross-bridge formation; it is neutralized by Ca^{2+} ions during muscle contraction.

Tubercle: A nodule, especially a bone, being smaller than a tuberosity.

Tuberosity: A protuberance, especially on a bone.

T-tubules: Any of the small tubules which run transversely through a striated muscle fiber and through which Ca^{2+} ion is released from the sarcoplasmic reticulum.

Upward rotation: *see* downward rotation. It is the opposite movement of the downward rotation.

Upward tilt: *see* downward tilt. It is the opposite movement of the downward tilt.

Vasomotor center: It is located in the medulla oblongata and regulates the vascular shunt mechanism. This basically redistributes blood during exercise and at rest accordingly.

Vector quantities: Quantity describing magnitude and direction, for example, force, impulse, velocity, acceleration, momentum, weight, lift, drag, thrust.

Velocity: Vector describing the change in position divided by the change in time.

Vital force: Vital pertaining to life and refers to vitalism, a thought that dates from Aristotle—that attempts (in opposition to mechanism and organicism) to explain the nature of life as resulting from a vital force peculiar to living organism and different from all other forces found outside living things. This force is held to control form and development and to direct the activities of the organism. In a larger content to understand vital force the following words are used by the people as well, for example, mental and spiritual energy, spirit, joy, enthusiasm, achievements, and so on.

Vital point pressure: *see kyusho.*

Watt: Absolute unit of power equal to the work done.

Weight: (1) The product of a mass of an object and the acceleration due to gravity. (2) The attractive force the earth exerts on a body on or near its surface.

Work–energy relationship: The physical amount of work done is equal to the change in energy. Work = $\Delta KE_{\text{Linear}} + \Delta KE_{\text{Rot}} + \Delta PE$.

Wrestling: An ancient sport, where the combatants try to throw or take-down their opponent and then to be fixed on the ground with their two scapulas. No kicking, striking, and any other dangerous action strictly forbidden.

Z-disk or Z-line: Any of the dark thin lines across a striated muscle fiber that mark the boundaries between adjacent sarcomeres.

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Conclusion

The reader is advised to see page xxxiii for Symbols which demonstrate italic and regular letters, for example, m = mass, m = meter, s = second, s = displacement, and so on. The author described attack and defense techniques. Some of them were complimented with counterattack techniques. For better understanding of the attack, defense, and counterattack techniques see explanation of the *defender* under the Glossary.

In this book, words such as estimate, approximate, or assuming about certain equations, factors, and so on, are used because of the large diversity of different martial arts and their techniques could not give us an exact answer. To analyze different techniques three dimensionally, the best way is to use different apparatuses such as force transducers, speedometers, and others. Furthermore, the descriptions of the techniques followed a 3-D explanation and their equations.

The reader should be aware that physical properties are described all the time for two active athletes. In this case for calculating force, moment of inertia, kinetic energy, power, velocity, acceleration, and so on, the author always (if it was neccessary) presented unpredictable situations from one participant to another, and vice versa. By taking these facts into consideration, the calculation was more difficult comparing to a single participant in sports such as running, jumping (track and field), swimming, platform jumping, kayaking—canoeing, ice-skating, and others.

Describing field sports where a ball is related to a participant such as basketball, soccer, volleyball, tennis, baseball, and so on, the biomechanic techniques are more complicated, but never when it's about the biomechanics of martial arts, where two subjects are thinking differently and they are almost in a permanent physical collision and have different goals.

The difficulty to establish any parameter for equation purposes in martial arts is demonstrated and explained in Section 10.1.8 with the "Lift-pull Foot Sweep" (*Harai-tsuri-komi-ashi*) technique and in Section 13.1.4.3 with the "Nr.2. Engagement, Parry, and Coupe Riposte with Lunge" technique.

The author put in all his knowledge to explain the simplified calculations for the complicated techniques herein, and most of the time giving examples for better understanding of the different techniques and their physical properties. Readers can be students of martial arts, graduate students, instructors, or college professors who could take the initiative and find other examples in different martial arts, where one can establish one's own knowledge on different parameters, and use this book as a guide to solve one's own examples.

In Part IV of the book, the author repeatedly described the names of the attacker (*Tori*), *Shite* or the defender (*Uke*), and many types of terminology in English and Japanese such as a "large skirt" a *Hakama*, "Karate jacket" a *Kimono,* or a "hand twisting maneuver" the *Kokyo-ryoku*, and other terminologies for the reason to better understand the words and to eliminate confusion.

The author hopes that this book will be welcomed by physical education students, sport and martial arts enthusiasts alike, and give them a larger horizon or perspective of knowledge related to the content described herein.

Addendum

GENERAL METHODOLOGY OF TEACHING MARTIAL ARTS

This part of the book describes some basic methodology of teaching three martial arts: (1) fencing, (2) karate, and (3) boxing. In these three combat sports, the methodology will cover not only techniques, but also tactics. Generally, the techniques and tactics are separately taught especially for the beginners or for the intermediate students. When an athlete has advanced in learning, then the teaching of the techniques goes along with the tactics.

Here are few important observations about each martial art: let us start with fencing. It is well known that learning fencing techniques involves the fencing master who teaches the fencer about the attacking and defending techniques. The fencing master works directly with his or her student mostly on a slow pace.

However in fencing between two high-caliber fencers, the victory belongs to the fencer who is better at tactical solutions. In this way to achieve victory, the fencer must adapt to the opponent's fighting style or create his own style. In brief, to be a winner, here are some important facts:

- Adaptability to a real opponent
- Create your own or go with the opponent's rhythm
- Learn the fighting distance
- Learn how to use the speed in your favor
- How to use false attack, feints and second intention, and so on.

Under Section 13.1. Modern (Olympic) Fencing, the second paragraph explains "Just like in any fighting art there are predetermined tactical solutions or better said pre-learned technical combinations." In the art of fencing, the technical combinations are learned during fencing lessons

with the fencing master. The tactical solutions are rarely or never taught, but can be explained by the instructor.

The other example, karate is a little different from fencing. In karate the student learns most of the time by observation and imitation and the instructor seldom touches the student's arm for guidance of the proper technique. In karate the technical combinations offer many times a good result for a good tactical solution. However in fencing, the technical combinations do not offer good tactical solutions. How should the reader understand tactical solutions for these two fighting arts (fencing and karate)?

Fencing involves just a fraction of a second for a tactical decision almost all the time; however, in karate the tactical decision takes more time, perhaps 1–2 s to react and then to execute the specific technical action. In fencing, executing one technique, a combination of techniques, or a feint and then a finalization of another technique may take a fraction of a second. In karate, the technique of a feint and then the finalization technique will take longer than a fraction of a second.

A third martial art is boxing. Similar to karate, boxing can be specified as a martial art with *Semi-permanent contact/link*. The author will enumerate the differences and similarities between karate and boxing.

The differences in these two martial arts (technical–tactical solutions) are mostly morphological, physiological, and psychological in nature for the practicing athlete. The author will not describe these differences in this book. However, the book deals with the three martial arts and their morphological/physical, physiological, and psychological nature.

The boxer is like a "time bomb" or a "robot." How should we understand these two words? The boxer is an athlete who must have his fighting style preestablished in order to reinforce his tactics on the opponent. So if he is an *in-fighter*, *out-fighter*, *brawler*, or *hybrid* fighter should mean that he will use one of these preestablished tactical solutions for a successful fight.

This means that the boxer is a kind of robot who preestablishes his tactical fighting style. It is almost impossible for a boxer to have some sudden tactical solution during a fight for the following reasons: Unlike in fencing or even karate the distance is much larger than in boxing. This distance problem creates difficulty to change a tactical solution. How should the reader understand this distance problem in creating or finding a new tactic?

By now the reader realizes that to use a new tactic you need a little time (split second or 1–2 s) to decide. Since the fencer or karateka relatively is distant and safe from the opponent means that he has the time requirement to change tactics by thinking and reacting using his reflexes.

This time requirement in boxing as previously stated is almost impossible, because of the permanent close distance between the two boxers and also because of the permanent hard contact on the athlete's body, the reflex reactions are slowed down. So what exactly happens during a fight?

Fatigue decreases the excitatory level of the muscle being hit and by this awareness and reflex responses to decide/act for a tactical solution the boxer does not have the luxury of time for reflex actions. Furthermore, the boxer will not have the time to create technical combinations.

As described earlier for a technical combination you need more time. In boxing, the technical combinations are learned in advance. You must bear in mind that in these three fighting arts, fencing, karate, and boxing, the execution time is not a slow down, but you as the executor slows down.

Simplicity of the technical arsenal in boxing does not require the most subtle tactical solution.

In the following paragraphs, the author will be more specific about the methodology of teaching these fighting arts and will highlight the general approach of teaching. The author will not deal with details of how to teach the techniques. It probably may require another book to describe the complexity of the teaching and learning process. Also those instructors who teach martial arts have their methodology developed during years of teaching. We will focus mostly on the methodology of teaching tactics; however, general guidance are given for instructors.

METHODOLOGY OF TEACHING TECHNIQUES

Here are some methodological points to follow:

1. Duration of a lesson
2. Intensity
3. Volume
4. Complexity of the technical elements
5. Methodology of principles: (a) active participation, (b) accessibility, (c) connection between explanation and demonstration, and (d) maintenance of the structure of the standardized lesson.
6. Standardization of the motor (technical) act.
7. The correlation of the effort and rest.

8. The analytical and integral teaching method.

9. The teaching of one technical element or the combined technical elements.

In addition, there are some more points that will not be discussed here. Importantly the above-described points are essential for the three martial arts mentioned earlier. The biggest difficulty in methodology of teaching martial arts is the methodology of teaching tactics. We will focus on these points.

METHODOLOGY OF TEACHING TACTICS

What Is Tactics?

Tactics is the total action of the different techniques executed rationally and timely by using the physical and psychological factors in competition for obtaining victory. Popularly the term tactics can be changed into the word "trick."

General problems using tactics are as follows:

1. The goal of tactics are: (a) The correct distribution of one's own effort during competition. (b) Creating conditions for applying the chosen tactical maneuver and diminishing one's own errors. (c) The athlete's adaptation to the competition rules and conditions and to opponent's style. (d) Annihilation of opponent's technical efficiency.

2. Tactical principles and its applications are: (a) Provocation of opponent's mistakes and capitalizes them. (b) Attacking opponent's weak spots. (c) Preparation of the decisive actions (attacks, defenses, counterattacks, feints, false attacks, etc.). (d) Ensure your weak body parts to be defended. (e) Anticipate opponent's actions. (f) Using surprise actions [related to (c)]. Enforce your own fighting rhythm on the opponent.

Tactics Used in Defense

1. Defense with direct retreat.

2. Defense with body turning (*Tai-sabaki*), only used in *Karate* and a little bit in boxing. Here the defender moves out from the attacking range of the opponent and counters him adequately.

3. Defense with direct advance. This form of defense is very efficient, but dangerous. The attacker cannot attack in good condition, because he is forced to retreat. In this case the attacker will attack hazardously.

4. Defense with a feint attack in retreat movement. The defender allows the attacker to initiate his attack, but he will be momentarily stopped by the defender's feint attack in his retreat movement. In this case if the attacker decides to attack, then the attack will not be decisive, because of the feint what the defender created during the attack. Briefly the attacker will be hesitant. The defender can defend and counter easily.

5. Defense with false attack.

6. Defense with off balancing (sweeping the attacker's front leg), then the defender continues his counterattack (only for *Karate*).

7. Defense with counterattack as a "stopped attack" into the attacker's attack.

8. Defense with blocking and counterattacking at the same time (for *Karate*) or defense with the attacker's blade exclusion and counterattack at the same time (for *fencing*).

Tactics Used in Attack

1. Direct attack with advance.

2. Direct attack to opponent's attack.

3. Attack into opponent's attack with body evasion (in *boxing*).

4. Attack in the opponent preparation who is ready to attack you.

5. Attack with "feints."

6. Attack with "false attack."

7. Attack with "false looking" (only for *Karate*).

8. Attack with "second intention."

9. Attack after the opponent finalizes his attack but comes up short. This tactic can be used as a tactic of defense. For a beginner, teaching this tactic is not recommended.

General Advice for Using Proper Tactics

In teaching tactics, the instructor must bear in mind the following aspects:

1. Student's personality (is he more an attacker, defensive, technical, thinker, etc.) also his nervousness or calmness during a fight.

2. Student's level of aggressiveness.
3. Student's dynamism.
4. Student's style.
5. Favorite techniques what the student can use or is using.
6. Ambidexterity.
7. Student's aerobic endurance capacity.
8. The percentage of using the favorite techniques of the student against any opponent or against a certain type of opponent.

The following terminologies/explanations will elucidate certain tactical thought and the related movements.

What Is a Second Intention Attack?

To launch a false attack, which will not follow the real strike of the opponent (as a first intention), but determining/forcing the opponent to use the proper blocking technique and by which gives us a "*counterstrike/punch known before*" and the attacker will block this counterstrike, then with tremendous speed will counterstrike the defender. There is a little difference using the second intention in fencing and in karate, here is the difference.

In fencing, for example, let us say the attack is a straight direct hit on the quart position (left lower part of the defender), his riposte after parrying the attack, almost definitively will come back also to the attacker's lower part, so the risk is minimal and the counter parade with the counter riposte is easy to be executed by the attacker.

On the other hand, in karate, let us say the attack is a straight kick to the stomach area, then the defender after blocking the attack his countertechnique will also be 80–90% a punch/strike. Countertechnique with the leg is very unlikely. From here the attacker will block the defender's countertechnique and then countering adequately. The big difference is about the countertechnique of the defender which is less probable in karate than in fencing.

What Is a Feint?

For karate: This is a body movement, usually an arm or leg movement toward the opponent's body which should give a real impression that will

be launched as an attack to the body area, where the arm or leg during the feint was extended. Usually the feint must be executed in a slow motion, for the reason to give enough time to the defender to observe the feint as a real attack.

For fencing: The feint is executed relatively in the same manner between two beginners or two intermediate fencers. However, the feint is executed with speed between two high-caliber fencers.

What Is a False Attack?

An attack with tremendous power and speed and with the real intention to hit the opponent, but it will stop short from the target. Using false attack is an excellent tactical maneuver for shortening the distance between the opponents. By repeating a false attack more than one time, the opponent will move closer and so the attacker can use a real attack which in fact will be longer to hit the target.

What Is a False-Looking Attack?

The attacker deliberately looks toward the defender's vital area, for example, the groin, however, he will attack the upper part of the body. The false-looking attack can be executed also at a far distance behind or lateral of the opponent. This tactic is only used in karate, but the rate of success is not so great.

What Is a Counterattack?

Popularly a "*Counterattack*" means a motion of blocking an attack, then executing a countertechnique (strike). It is inaccurate! When you blocked an attack and counter back, then the correct terminology is; "*Counter the attack*."

The counterattack is an attack in itself. In a simple way, after an attack was launched by the opponent and did not reach the opponent, then the attacker is in retreat, the defender takes over the action of attack or simply a counterattack.

In fencing, the terminology is simple:

1. Attack—parry—riposte (here there is no counterattack involved).
2. Attack (short from the target)—no riposte—*counterattack* from the defender (who took it over the initiative of an attack).

THE SPECIFIC METHODOLOGY OF TEACHING (PREPARATION) KARATE TACTICS

It is well known that the first aspect of teaching tactics is to teach simple technical combinations and later on more complicated combinations. Here are a few steps in order of importance in teaching tactics in karate:

1. Learning very simple combinations without opponent.
2. Learning simple combinations with an inactive opponent.
3. Practice nos. (1) and (2) in a straight line.
4. Practice nos. (1) and (2) in a circular movement.
5. Practice one of the numbers sited with a semi-active or active opponent, who for instance can counter/attack in the simplest way.
6. Practice no. (5) by establishing certain kind of techniques and restricting others. Set up mandatory techniques for blocking and for attack.
7. Practice from the above points with more complicated technical combinations and learning how to keep short, medium, and long distance between the opponents.
8. Allow a free fighting practice only with certain areas of the body to be attacked and/or a certain technique to be used.
9. Practice free fight with an opponent who is less skillful than you.
10. Practice free fight with different opponents.

Note: The reader could ask if there is a tactical solution between the wrestlers, judo, jujutsu, and sambo athletes. The answer is 90% NO. These martial arts belong to the definition of the *Permanent Contact/Link* described in Summary PART IV.

Let us consider wrestling. At the beginning of the contest there is a lot of pushing, grabbing, and so on, and simply there is no possibility to create any tactical solution. Once a wrestler grabs the opponent and manages to take him down or put him in a submission (bridge) position, then again the chance is restricted for only one technical procedure. Similar problems occur with judo, jujutsu, or sambo. In these three martial arts there

is a remote possibility of tactically maneuvering an opponent, as in judo. Let us assume that both judoka hold the basic right-handed grabbing position. The tactics can occur if one of the judoka will hold the left-handed grabbing position, but still execute a right-handed throwing. Another possibility is to change the right-handed positions and fake an attack to the left, after that execute the attack to the right. This was a case for my best student Steven Nagy who captured his first Romanian Junior Champion title. In Aikido there are no tactical solutions at all.

CONCLUSION

The method of teaching is vast and is changing almost every year or better said there are some changes to be improved in the teaching–learning experience. The time length of teaching enables a good coach to try and experience new solutions. Regarding teaching tactical solutions it is primordial that at the beginning of teaching an intermediate or advanced student it is better not to teach complicated tactics but just teach the simplest *trick* what the student can comprehend and can deliver during a fight.

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Index

B

F

G

H

L

M

U

V

W

Y

Z